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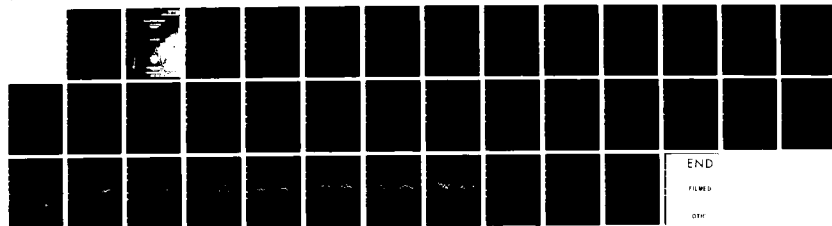
BROADBAND PILLBOX ANTENNAS(U) NAVAL RESEARCH LAB
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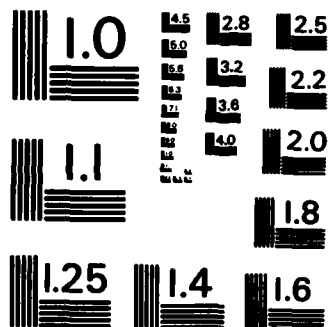
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<p>The possibility of designing very broadband pillbox antennas has been demonstrated. It was also shown that the operating bandwidth of the existing IFF (pillbox) antenna, AS-1065/UPX, can be improved by a simple modification of the existing feed. Additional modifications are suggested to further improve the performance at the low frequency end.</p>				
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BROADBAND PILLBOX ANTENNAS

1. INTRODUCTION

Pillbox antennas [1] have found widespread use in radar and communication applications. The most common type of pillbox antenna is that used to collimate the energy from a point source, placed at the focus of a parabolic cylinder connecting two parallel plates, into a plane wavefront. There are two major disadvantages in using this simple pillbox, some times called single layer pillbox. First, the pillbox feed, by obstructing the aperture, lowers the gain and raises the sidelobes of the pattern. Second, energy reflected from the back plate of the pillbox to the feed makes the broadbanding impossible without the use of a vertex plate, which causes further degeneration in the pattern. These limitations are eliminated, to a large extent, in a double layer (or folded) pillbox. However, pillboxes having an octave or more bandwidths have not been reported in the literature. It is the purpose here to report on the results of a study on the bandwidth limitations of folded pillbox antennas and to present a design which provides a wideband pillbox antenna. The results were used to build a simulated pillbox using waveguides to show the practical feasibility of building a broadband double layer pillbox. The experimental results indicated that the existing pillbox antenna AS-1065/UPX [2], which is being used as an IFF antenna, can be modified to make it broadband by simply replacing the existing feed with a wider feed.

A pillbox antenna AS-1065/UPX was then modified using a new feed. The experimental results showed that the performance bandwidth of the AS-1065/UPX is indeed improved by simple modification of the feed. The results also indicated that further improvement, in the low frequency end, is possible by using a slightly wider feed and also by increasing the spacings between the metallic webs (which exists in the aperture of the AS-1065/UPX antenna) or by removing them completely. However, this additional work was not undertaken due to funding limitation.

2. BROADBAND DOUBLE LAYER PILLBOX

In a double layer pillbox, the feed is located in one layer with the second layer containing the radiating aperture, as shown in Fig. 1. In such designs, the energy is transferred from one layer to the other by 180° bend. Therefore, the amount of reflection back into the feed system is reduced.

The bandwidth of the double layer pillbox depends on the reflections at the bend, the nature of the feed, and the reflections at the radiating aperture. We will discuss these in what follows.

2.1 Broadband 180° Bend Design

Fig. 2 shows the 180° bend which is usually used in double layer pillboxes. The particular design objective of the bend is the minimization of reflections back toward the source. Since the microwave energy will be striking the bends in the pillbox at different angles of incidence, the bends must have a low coefficient of reflection for both normally and obliquely incident rays. Also, for broadband applications, the reflections

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must remain small over a wide range of frequencies. According to Taggart and Fine [3], the requirement for low reflection as a function of angle of incidence and as a function of frequency are interrelated and lead to similar design parameters for TEM mode propagation. They showed that the transmission coefficient of a plane wave of wavelength λ striking the bend at an arbitrary angle θ to the normal is exactly the same as for another plane wave of wavelength λ' striking the bend at normal incidence, where $\lambda' = \lambda/\cos\theta$. A bend which is broadband (for normal incidence) over a range of frequencies should, therefore, have excellent transmitting qualities at a single frequency for a wide range of variable angles of incidence.

Taggart and Fine [3] give curves of d/a vs $\lambda g/a$ for reflectionless bends (where "a" is the spacing between the parallel plates and "d" is the septum spacing). For the double layer pillbox, $\lambda g = \lambda/\cos\theta$, where λ is the free-space wavelength and θ is the angle of incidence of the particular ray considered. For broadbanding, the spacing between the plates "a" should be smaller than $0.2 \lambda g$. Taggart and Fine [3] gave measured curves which show the relation between d/a , s/a and $\lambda g/a$ (where s is the septum thickness). Their figures 5 and 6 are reproduced here as Figs. 3 and 4. The curves are limited to $\lambda g/a < 7$. However, they can be used to choose approximate values for a , d and s for broadband operation. If needed, these approximate values can be used in devising an experiment (to simulate a double layer pillbox) using waveguides and then experimentally determine the bend parameters which result in broadband operation over a specified band of frequencies, as discussed later.

For broadband operation, it was noted earlier that the spacing between the plates "a" should be smaller than $0.2 \lambda_h$ (λ_h = wavelength at the highest frequency of interest, i.e., 1600 MHz), then the broadband requirement will be satisfied for other frequencies and for all angles of incidence. Therefore "a" is chosen as 1" ($= .127\lambda_h$), which is also the spacing used in the existing pillbox. This results in $\lambda_h/a \approx 7.87$ and $\lambda g/a$ for any other frequency in the required band will be greater than 7.87. Taggart and Fine give results only up to $\lambda g/a = 7$. However, from Fig. 3 (their Fig. 5), it may be noted that for $\lambda g/a > 7$ the curves are quite flat. So, for a matched bend, at a mid frequency of 1080 MHz, d/a should be chosen to be approximately 0.6 (from Fig. 3) for $s/a = .119$. By choosing these parameters for the bend, it may be noted from Fig. 4 (Fig. 6 of Taggart and Fine) that the VSWR will be less than 1.25 for the whole frequency range and for all the angles of incidence.

2.2 Broadband Feed Design

For broadband operation of a double layer pillbox, the nature of the feed is the most important single factor. Most common feeds are rectangular waveguides with coaxial input. There are a number of methods [4] available to broadband the transition from coaxial input to the rectangular waveguide. One method is to use a ridge-block transforming junction, which gives about 2.2:1 bandwidth for a voltage standing wave ratio (VSWR) of less than 2:1. For higher bandwidth, a ridge waveguide is needed [4] as a feed. However, ridge waveguide is not practical to implement in the present case because of the limitations in space. Therefore, a ridge-block transforming junction is chosen as a broadband feed for the double layer pillbox. The details of the procedure used in designing such a junction can be found in reference [4]. Therefore, only a brief discussion on the design of the junction is included here.

Figure 5 shows the transforming type of junction. Where; Z_0 is the characteristic impedance of the coaxial line (assumed to be 50Ω in our case); Z_{01} , Z_{02} , and Z_{03} are the characteristic impedances of the various segments of the waveguide; f_{c1} , f_{c2} and f_{c3} are the cut-off frequencies of those waveguide segments as shown in Fig. 5. The lengths L_{g2} and L_{g3} are equal to quarter wavelength in their respective waveguide segments.

Our interest is in the frequency range of 600 to 1600 MHz. So the cut-off frequencies $f_{c1} = f_{c3}$ are assumed to be 540 MHz (90% of 600 MHz). This determines the width a_1 of the waveguide to be 11". The thickness b_1 of the waveguide feed is determined by the spacing between the parallel plates in the pillbox antenna. This was determined, in the previous section, to be one inch. With these dimensions, the remaining parameters of the junction can be found as explained in the Appendix.

Using the above design parameters, a coaxial to waveguide transition, as shown in Fig. 6, was built. To determine the performance of the transition over a frequency band, voltage standing wave ratio (VSWR) on the coaxial line was measured using coaxial slotted line with the waveguide terminated with a matched load. The results are also shown in Fig. 6. Note that the experimental model is scaled down by 2:1. So, all the dimensions are one-half of the design values and the frequency of interest is scaled up by 1.2 to 3.2 GHz. From Fig. 6 it is clear that in the low frequency side the VSWR is less than 2. However, there is a resonant peak around 2.9 GHz. This was attributed to the fact that the length of the short circuiting block L_{g3} becomes a one-half wavelength at 2.93 GHz and effectively shorts the transition junction. Therefore, it was conjectured that the length L_{g3} should be shortened to improve performance at the high frequency end. An optimum value of L_{g3} was determined experimentally so that the VSWR is less than 2 over a frequency band of 1.2 to 3.2 GHz. The optimum value for $L_{g3} = 2.128"$ (1.064" for the scale model). Fig. 7 shows the transition and the experimental results obtained with the optimum value of L_{g3} . These results show that a broadband waveguide feed can be designed, which can be used in a pillbox, over a frequency band of 1.2 to 3.2 GHz.

2.3 Experimental Simulation of Double Layer Pillbox

Earlier it was discussed that the reflections from the 180° bend can be reduced by properly choosing the dimensions of the bend. Using the dimensions of the pillbox and the bend which were obtained earlier, an experiment was performed using the broadband feed discussed in the previous section to determine the effect of the 180° bend. To do this, one need not build a pillbox antenna. Also, impedance measurements in parallel plates with straight 180° bends are difficult to make. However, Taggart and Fine [3] showed that it is possible to reduce the problem to the simpler one of investigating 180° bends in waveguides, by showing that the electromagnetic fields in the parallel plate bend and those in the corresponding waveguides are equivalent. This equivalence makes it possible to perform experiments in waveguides in order to obtain information concerning the parallel plates.

Fig. 8 shows the experimental set up with two waveguides with a gap "d". The two waveguides were soldered together with the adjacent walls cut back and rounded to form the septum. The coaxial to waveguide transition developed earlier was used as the input to the top guide. The lower

waveguide is terminated in matched load while making impedance (VSWR) measurements over the frequency band of 1.2 to 3.2 GHz. The results are shown in Fig. 9. The curve in Fig. 9 is quite similar to that of Fig. 7, except that there is a rapid but small modulation visible in Fig. 9. This small difference indicates that the contribution (due to reflections) of the bend is quite small and can be ignored for all practical purposes.

2.4 Radiating Aperture Mismatch

The other factors which will affect the impedance of the pillbox antenna are the reflections at the radiating aperture due to the mismatch between the antenna, the free space, the weatherizing cover, and other aperture modifications [5]. These factors will not be considered here because there are no plans to build a new type of pillbox antenna with broadband characteristics. Only simple modifications to the existing antenna are contemplated.

3. EXPERIMENTAL RESULTS OF THE MODIFIED PILLBOX ANTENNA AS-1065/UPX

Fig. 10 shows the input VSWR of the original AS-1065/UPX. The solid curve is the VSWR of the antenna as received. The dotted line curve represents the antenna VSWR with 11/16 inch rod, which is used for aperture matching in the original antenna, removed from the antenna aperture. As can be noted, the VSWR is unacceptably high below 750 MHz. This is partly attributed to the fact that the cutoff frequency of the original feed is 655 MHz (the width of the waveguide feed was 9") and the VSWR is high near and below cutoff. Therefore, it was decided to modify the feed by increasing its widths to 11 inches (the corresponding cutoff frequency is 540 MHz) and optimizing feed parameters, as discussed earlier, to increase its bandwidth. Fig. 11 shows the original and new feed dimensions.

Fig. 12 shows the input VSWR curve of the modified AS-1065/UPX with the wider feed. As expected, the VSWR curve is much improved in the low frequency end. However, there existed a small peak around 625 MHz. First it was not clear why this peak and other small peaks existed. However, it was later conjectured that some mismatch existed between the antenna aperture and free space. After close scrutiny, it was found that a number of metallic webs are used [2] to keep metallic baffles in place. These metallic webs (spaced 10" apart) and baffles formed a series of waveguides with a cutoff frequency around 600 MHz, causing aperture mismatch around and below 600 MHz. It is believed that the peaks at 625 MHz and 700 MHz may be the result of the combined effect of the aperture mismatch due to the spacing of metallic webs and the mismatch due to the closeness of the feed cutoff. Hence, it is possible that the VSWR can be improved further at the low frequency end by increasing the feed width to about 12" and increasing the spacing of the webs to at least 12" (or by eliminating them). Unfortunately, the limited time and funds available for this project did not allow any additional work.

It was, however, decided to make gain and pattern measurements with the modified AS-1065/UPX to further assess the feed modification. Figs. 13 to 23 show the radiation patterns at different frequencies over the frequency range of 600 MHz to 1600 MHz. The patterns are reasonably well behaved over this broad frequency range. (For frequencies of 900 MHz and

below, a receiver was not available and a broadband detector was used. The patterns are noisy due to some interfering signals from the nearby national airport below 900 MHz.) For frequencies 1000 MHz and above, a receiver was used to amplify the received signals and a horn antenna was used as a gain standard in measuring modified pillbox gain. Fig. 24 shows the absolute gain of the modified pillbox antenna as a function of frequency. The results show that the pillbox antenna can be modified for use over the frequency band of 600 to 1600 MHz.

4. TRIPLE LAYER PILLBOX

It appears that the feed bandwidth is the limiting factor in designing a broadband pillbox. Therefore, it may be necessary to use two feeds, one for low frequency and another for high frequency, to further improve the pillbox antenna bandwidth. In the two-layer pillbox, two feeds may be placed on either side of the parabolic focus. However, moving the feed off focus results in decrease in gain and increase in sidelobes. Designing a triple layer, bifocal pillbox will eliminate this problem as will be discussed later.

A double layer pillbox is a two dimensional equivalent of a front fed parabola. Similarly, a triple layer pillbox is equivalent to a two dimensional cassegrain or gregorian reflector. Fig. 25 shows a sketch of a triple layer pillbox. Feed or feeds are located in the first layer and the energy is transferred to the second layer by the first 180° bend. The energy from the second layer is transferred to the third layer by the second 180° bend. If the curvature of the first bend is hyperbolic and the curvature of the second bend is parabolic, the resulting triple layer pillbox will have a single focal point, where a feed may be placed. By shaping the curvatures of the first and second bends, different triple layer pillboxes with different properties can be obtained. One such design is to shape the curvatures [6] such that a desired aperture distribution can be obtained for a specified feed pattern. This type of design may be needed for designing low sidelobe or high efficiency pillboxes. Another type of design may be used to shape the curvatures such that the triple layer pillbox has two focal points, similar to a bifocal dual-reflector antenna [7]. Fig. 26 shows the sketch of a triple layer pillbox, where A and B are two focal points. The curvatures of the first and second bends can be designed, using the procedure given in [7], such that the horizontal beam is pointed at an angle α to the antenna axis when the feed is placed at the focal point A and the beam is pointed at an angle $-\alpha$ to the antenna axis when the feed is placed at the focal point B. So, there is a small beam displacement depending on the feed used. To improve the bandwidth of this pillbox antenna, for example, one could use a feed at focal point A to cover the low frequency end and a feed at focus B to cover the high frequency end. In this way, one could improve feed bandwidth by at least an octave.

5. RECOMMENDATIONS AND CONCLUSIONS

The feasibility of designing very broadband pillbox antennas has been demonstrated. It was also shown that the bandwidth characteristics of the existing IFF (pillbox) antenna AS-1065/UPX was improved by a simple modification of the existing feed. The experimental results suggested that further improvement, at the low frequency end, is possible by using a

slightly wider feed waveguide and also by increasing the spacing of the metallic webs (which exists in the radiating aperture of the AS-1065/UPX antenna) or removing them completely. Other possible designs of pillbox antennas for broadband applications are also suggested.

6. REFERENCES

1. W. Rotman, "Wide-Angle Scanning with Microwave Double-Layer Pillboxes," IRE Transactions on Antennas and Propagation, Vol. AP-6, pp. 96-105, Jan 1958.
2. Technical Manual for Antenna AS-1065/UPX, Dept of the Navy, Bureau of Ships, NAVSHIPS 93560, Jan 1960.
3. M.A. Taggart and E.C. Fine, "Parallel Plate Bends", Massachusetts Institute of Technology, Radiation Laboratory, Rpt. No. 760, Sep 1945.
4. Radio Research Laboratory Staff of Harvard University, "Very High-Frequency Techniques," Vol. II, McGraw Hill, NY, pp. 717-727, 1947.
5. J.S. Ajioka, "The Development of an Integral MK X IFF Antenna for Low-Frequency Radar," R&D Rpt 534, US Navy Electronics Laboratory, San Diego California, 5 Jan 1955. (AD-086 678L)
6. V. Galindo, "Design of Dual-Reflector Antennas with Arbitrary Phase and Amplitude Distributions," IEEE Trans. Antennas and Propagation, Vol. AP-12, pp. 403-408, July 1964.
7. B.L.J. Rao, "Bifocal Dual Reflector Antenna," IEEE Trans. Antennas and Propagation, AP-22, pp. 711-714, Sep 1974.

APPENDIX

COAXIAL TO WAVEGUIDE JUNCTION DESIGN

Figure 5 in the text shows a transforming type of junction. The procedure outlined in reference [4] is used in designing that junction. To obtain improved bandwidth, a ridge block transforming junction [4] will be used. For this type of junction it is recommended that $f_{c3} = f_{c1}$ and $f_{c2} = 0.8f_{c1}$. Lower value of cut-off frequency for f_{c2} is obtained by loading the waveguide with a ridge block. Since the interest is in the frequency band of 600 to 1600 MHz, $f_{c1} = f_{c3}$ is chosen as 540 MHz (90% of the lowest frequency of interest). This determined the waveguide width a_1 to be eleven inches. The thickness of the waveguide feed b_1 is chosen as one inch (because the spacing between the parallel plates of the pillbox antenna was chosen as one inch). So, the guide impedance at mid-frequency, $f = 900$ MHz, is given by

$$Z_{o1} = 60\pi^2 \frac{b_1}{a_1} \frac{1}{\sqrt{1-(f_{c1}/f)^2}} = 67.3 \Omega$$

To transform this to 33 ohms, we need the characteristic impedance Z_{o2} of the ridge section to be

$$\begin{aligned} Z_{o2}^2 &= Z_{o1} \times 33 \\ \text{or} \quad Z_{o2} &= 47 \text{ ohms.} \end{aligned}$$

To find the parameters of the ridge block, the figure 26.29 of reference [4] will be used. In order to do that, a modified impedance $Z'_{o2} = Z_{o2} \times 0.136 \times a_1/b_1$ is needed (see reference [4], page 679) and is found to be $Z'_{o2} = 70.5$ ohms. Then, the characteristic impedance at infinite frequency is given by

$$Z_{\infty} = Z'_{o2} \sqrt{1 - (f_{c2}/f)^2} = 61.8 \text{ ohms.}$$

Knowing Z_{∞} and f_{c1}/f_{c2} , one can obtain the ridge block dimensions by using Fig. 26.29 of the reference [4] and are given as

$$\frac{a_2}{a_1} = 0.2 \text{ and } \frac{b_2}{b_1} = 0.44$$

where a_2 is the width of the ridge block and $b_1 - b_2$ is the thickness of the ridge block. Therefore,

$$\text{the width of the ridge block} = 2.2''$$

$$\text{and the thickness of the ridge block} = .56''$$

Since L_{g2} and L_{g3} should be respective guide quarterwave lengths at $f = 900$ MHz, they are found to be

$$L_{g2} = \frac{1}{4} \frac{\lambda}{\sqrt{1-(f_{c2}/f)^2}} = 3.74 \text{ inches}$$

and

$$L_{g3} = \frac{1}{4} \frac{\lambda}{\sqrt{1-(f_{c1}/f)^2}} = 4.1 \text{ inches .}$$

This completes the design of the coaxial to waveguide junction.

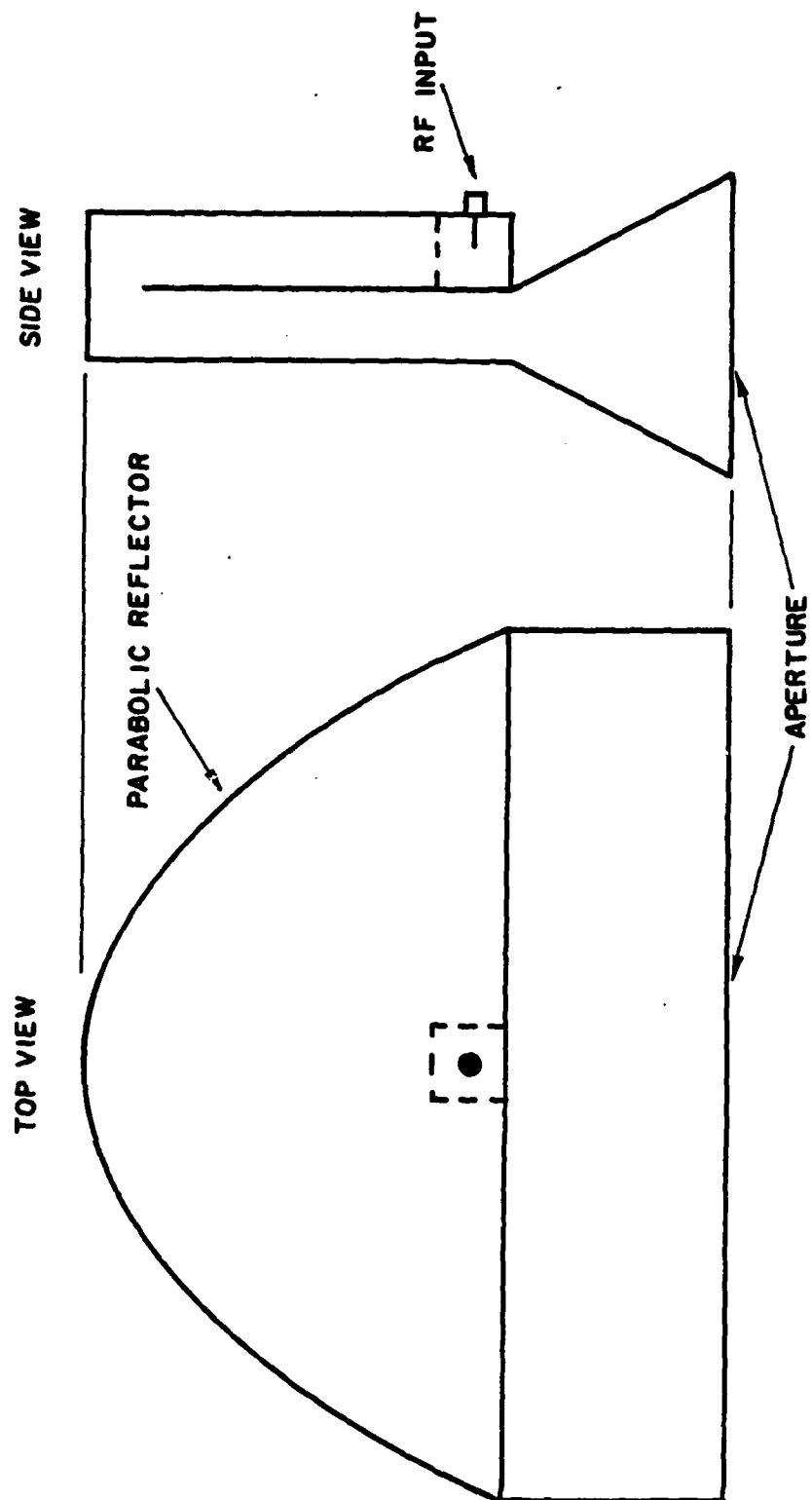


Fig. 1 — Folded pillbox antenna

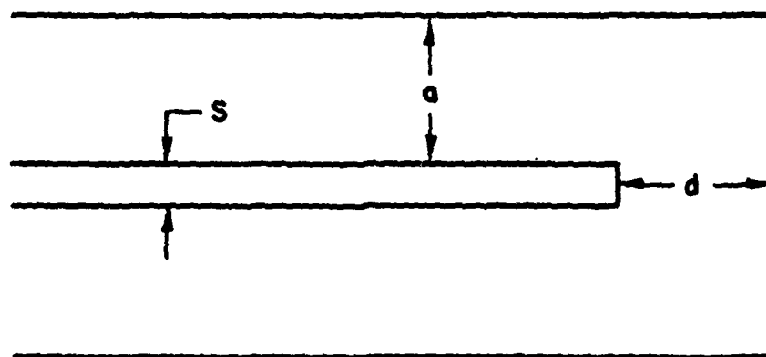


Fig. 2 — 180° Bend

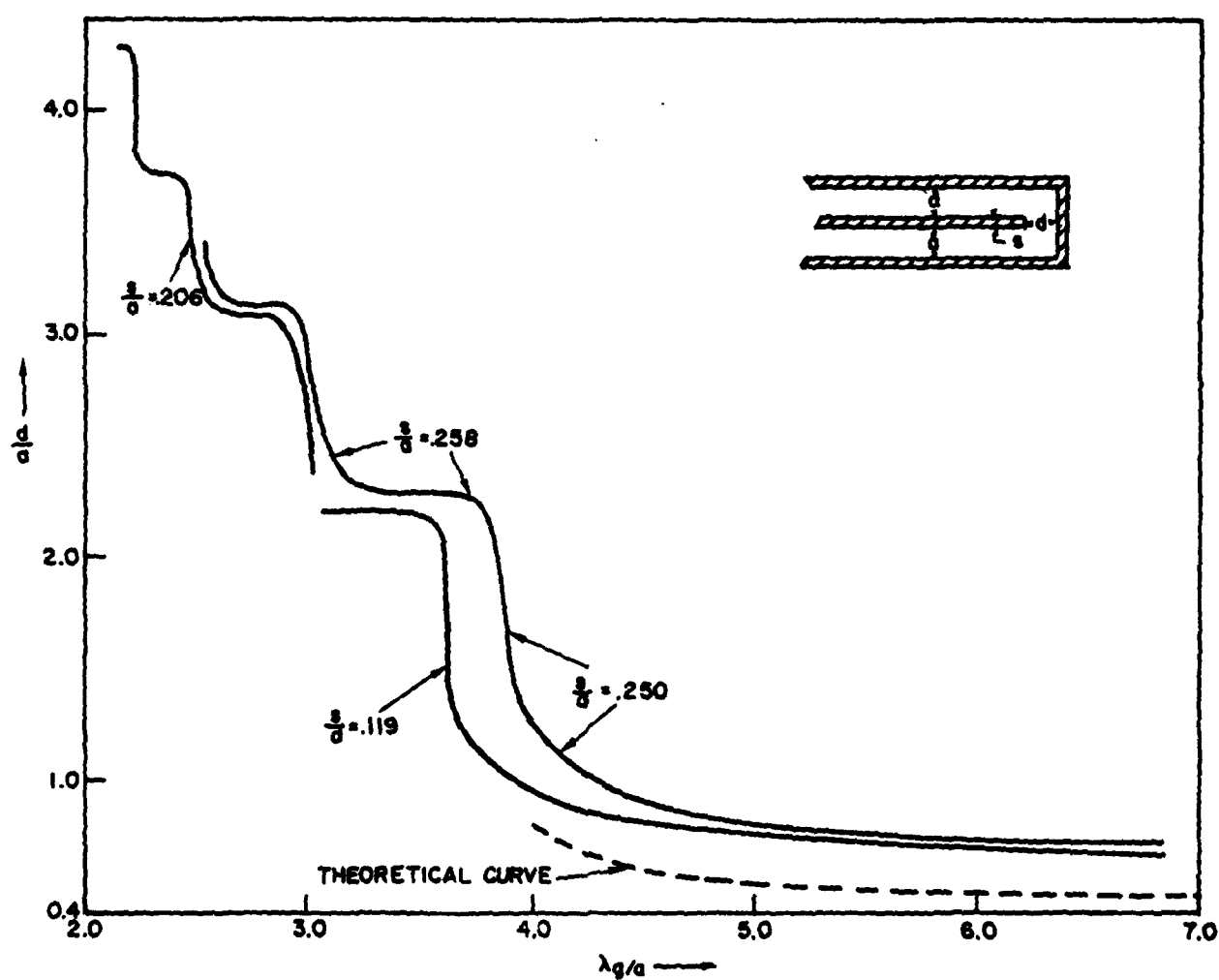


Fig. 3 — Variation of d with wavelength in matched bend

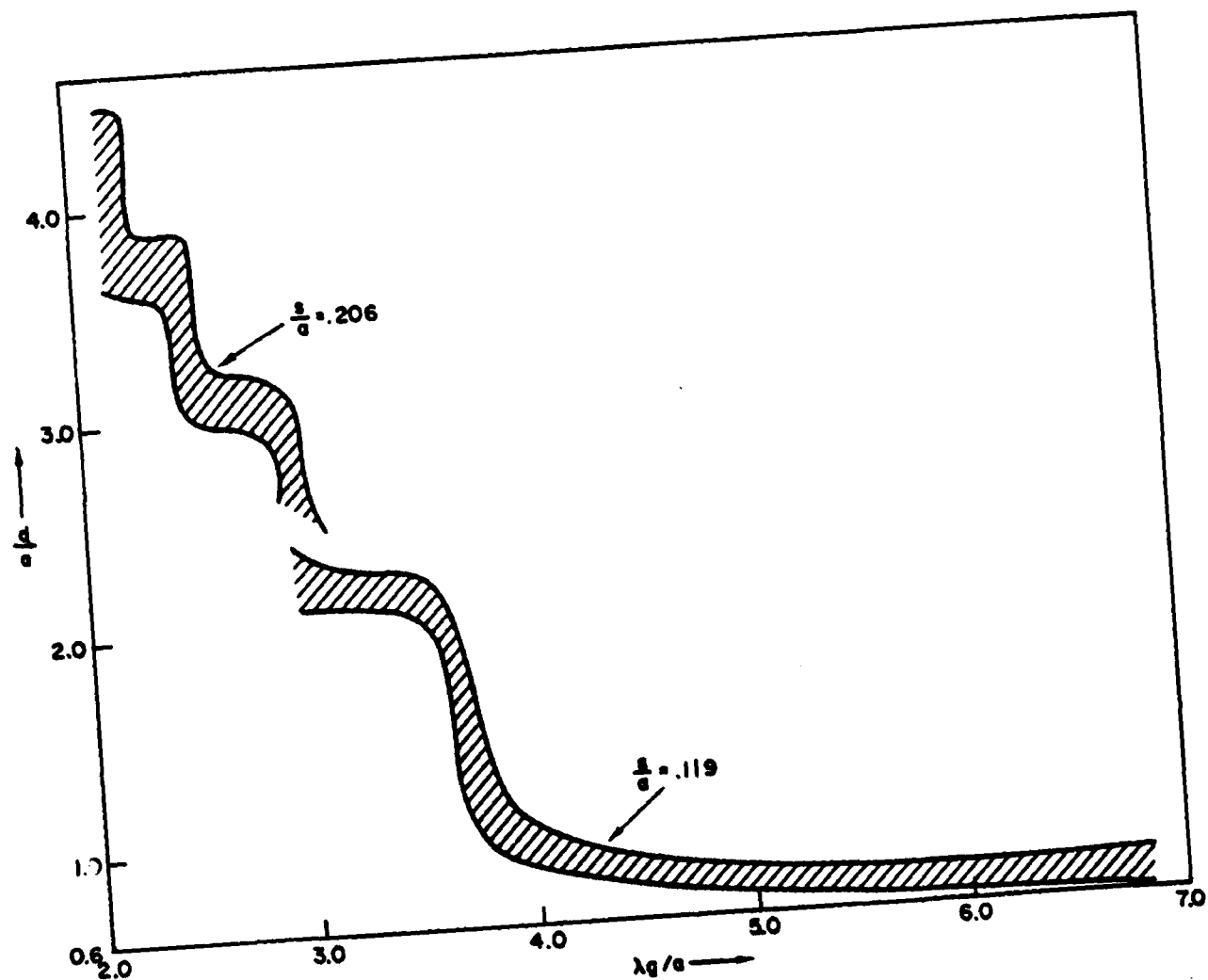
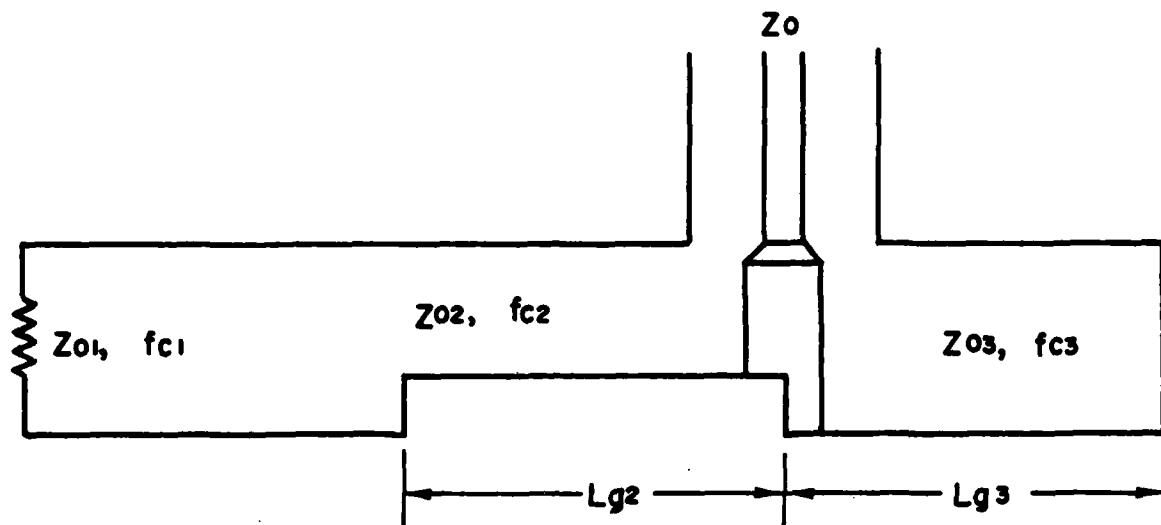
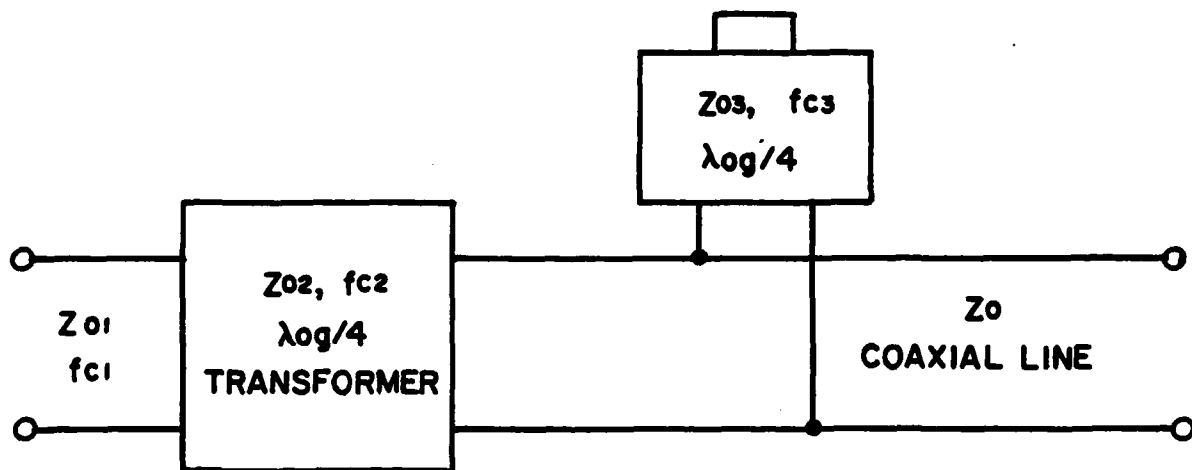


Fig. 4 — Dimensions of bends for which $(SWR)^2 < 1.5$



(a) Structure



(b) Approximate equivalent structure

Fig. 5 — Transforming type of junction

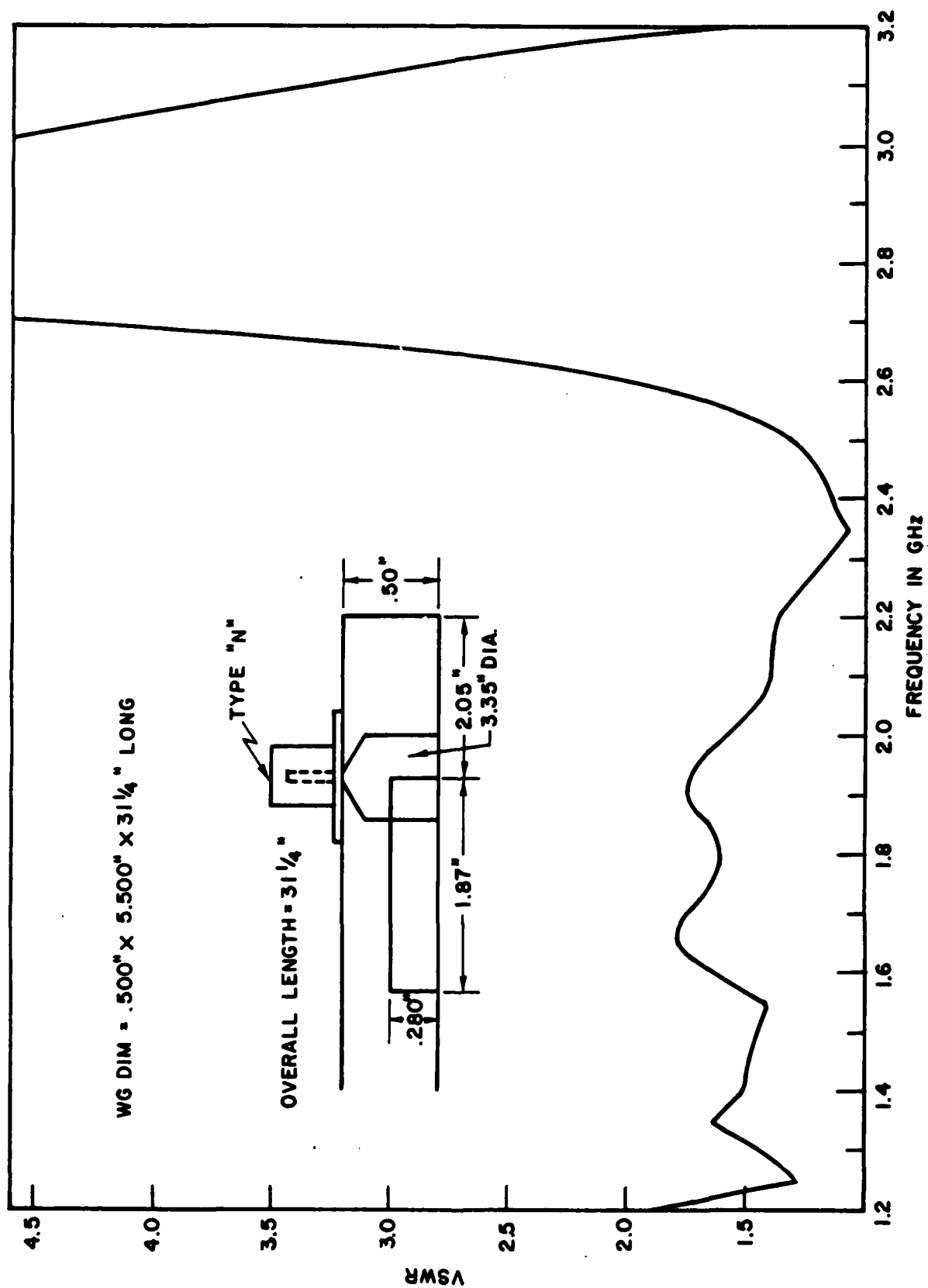


Fig. 6 — Transition — type "N" to waveguide

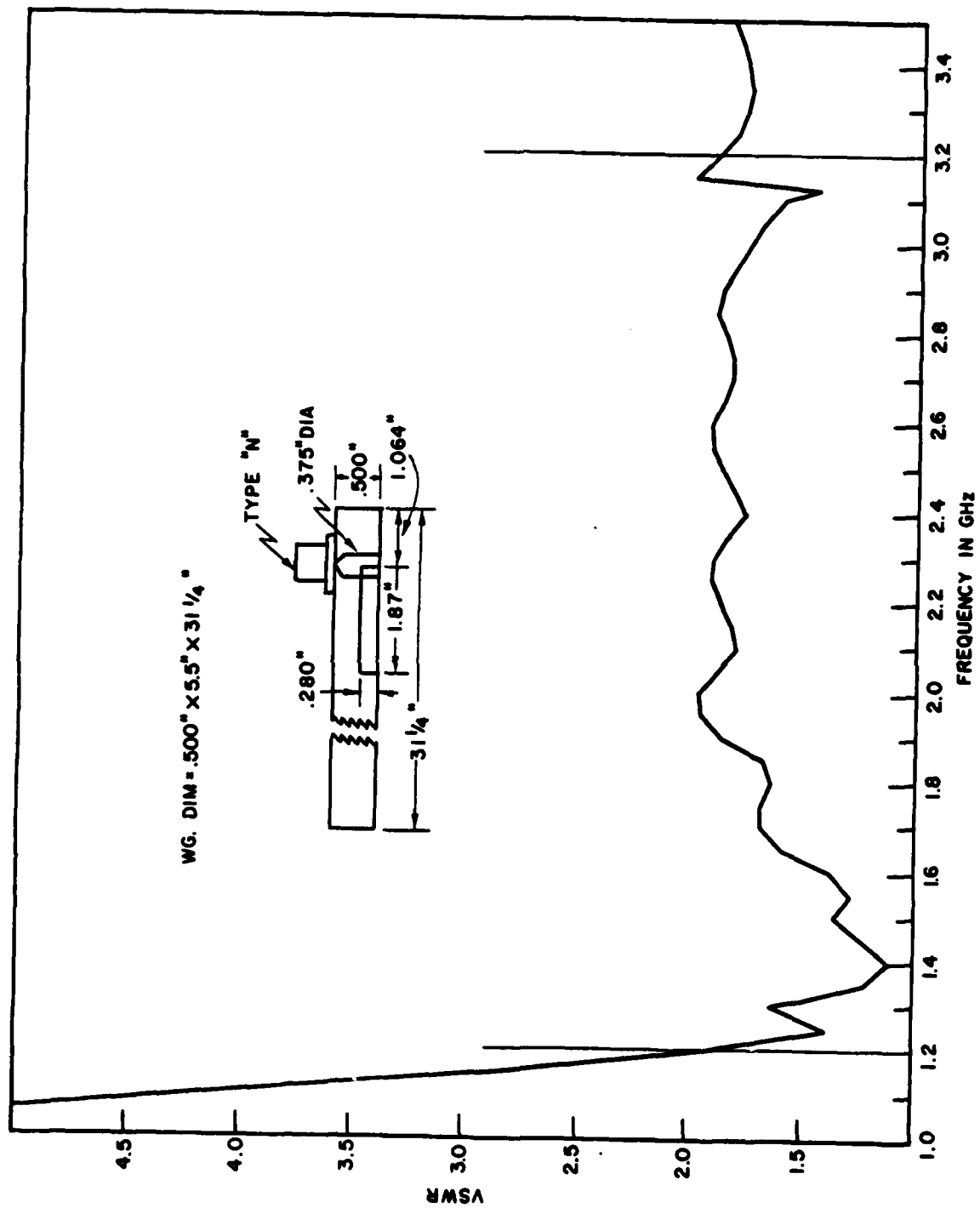


Fig. 7 — Transition — type "N" to waveguide

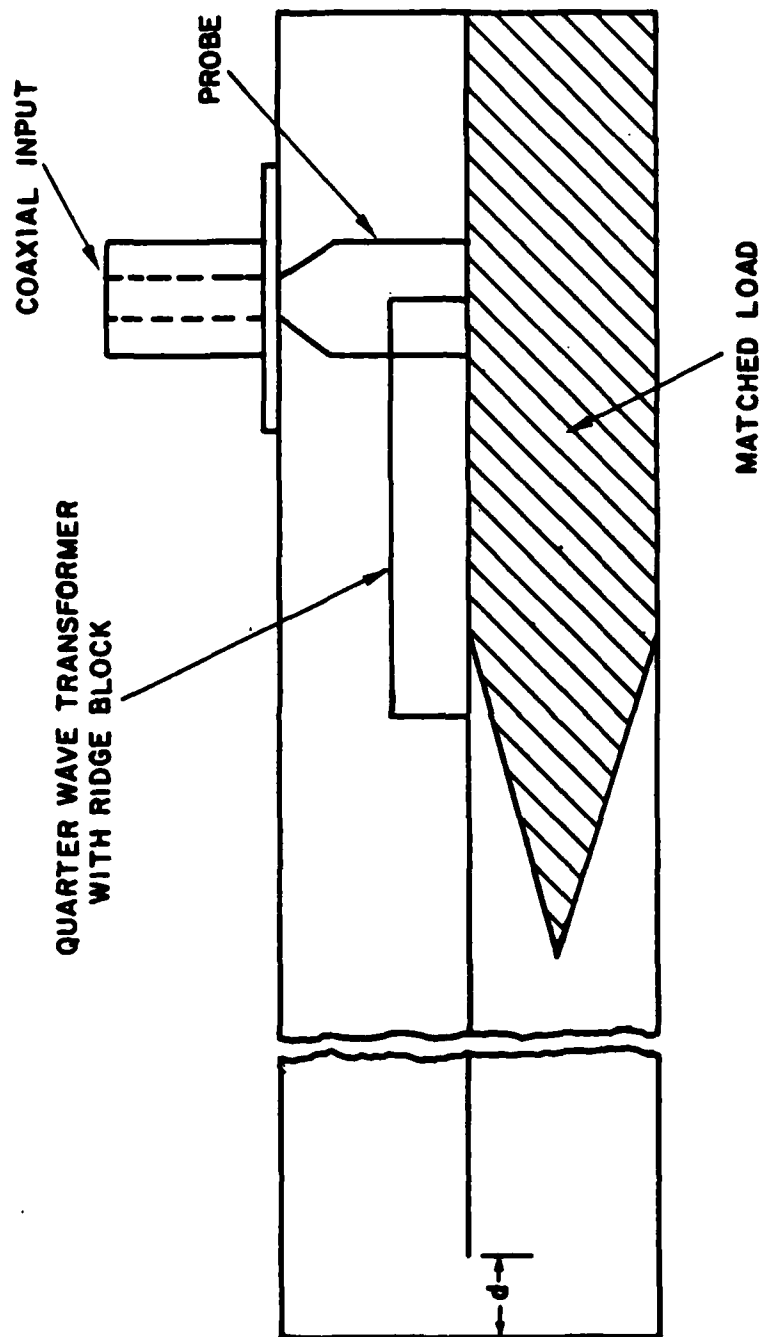


Fig. 8 — Waveguide simulation of double layer pillbox

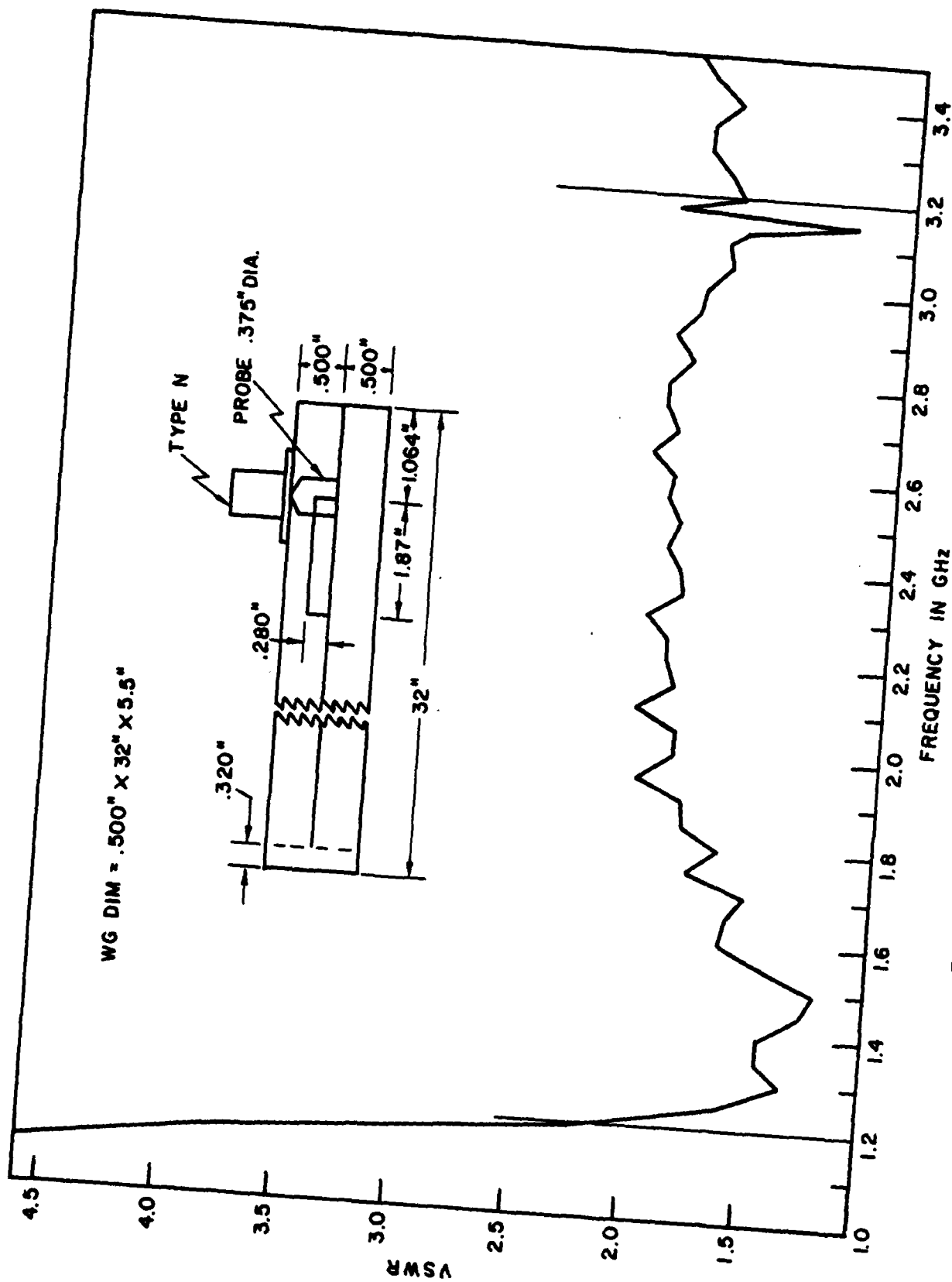


Fig. 9 — Transition — type N to waveguide + 180° bend

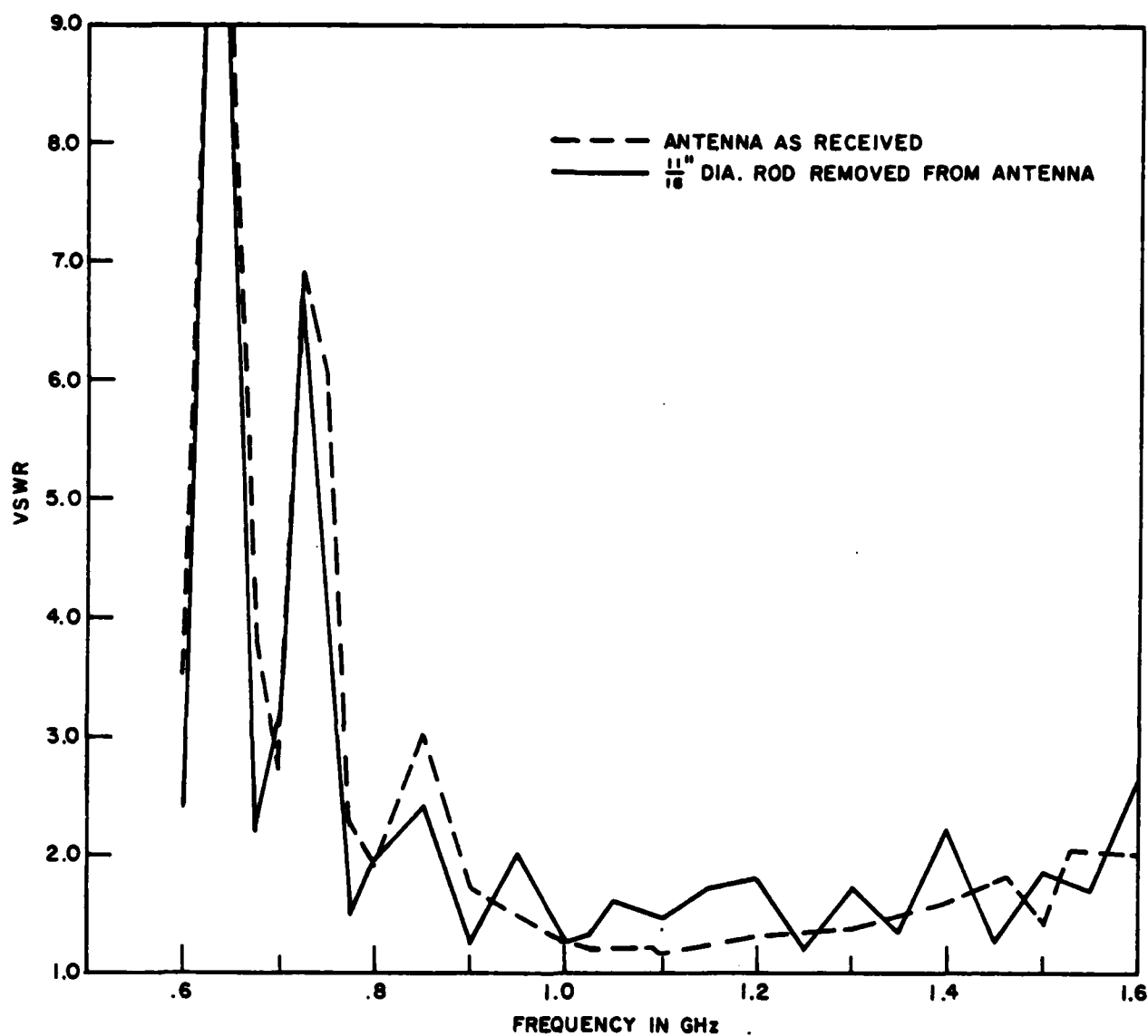
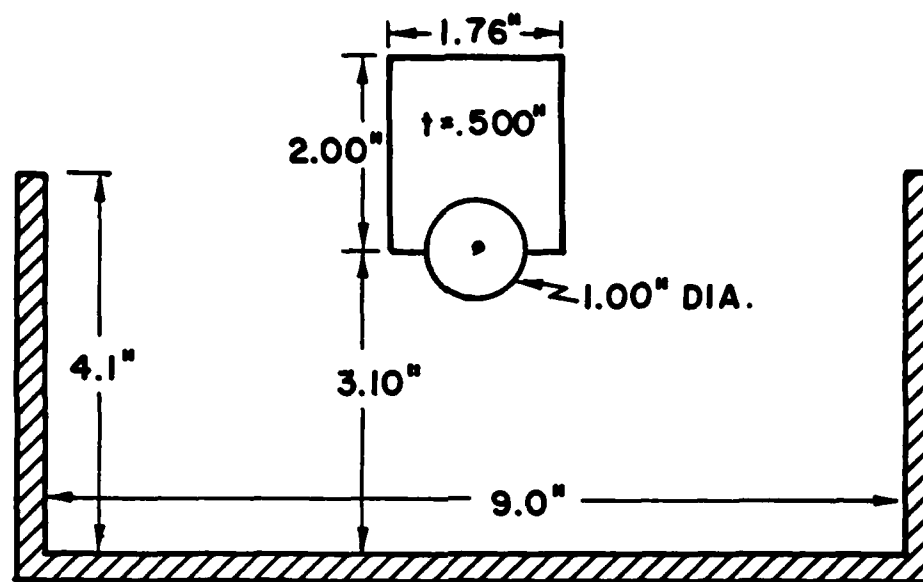
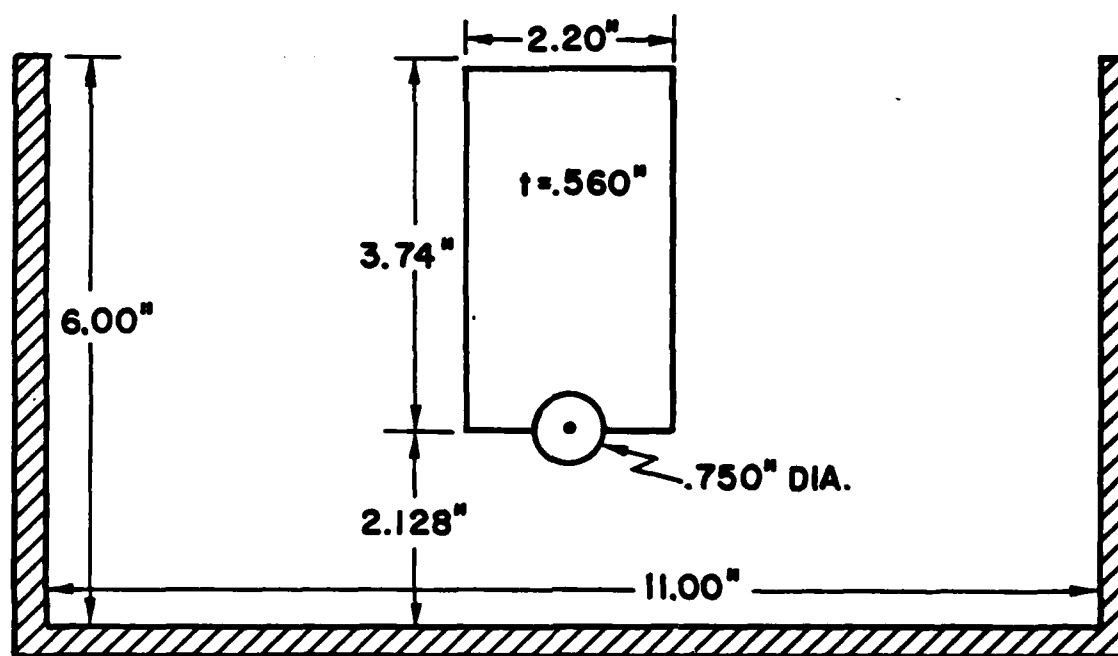


Fig. 10 — AS-1065 antenna: input VSWR vs frequency



ORIGINAL FEED FOR AS-1065 ANTENNA



NEW FEED FOR AS-1065 ANTENNA

Fig. 11 - Dimensions of the original and new (modified) feeds for AS-1065 antenna

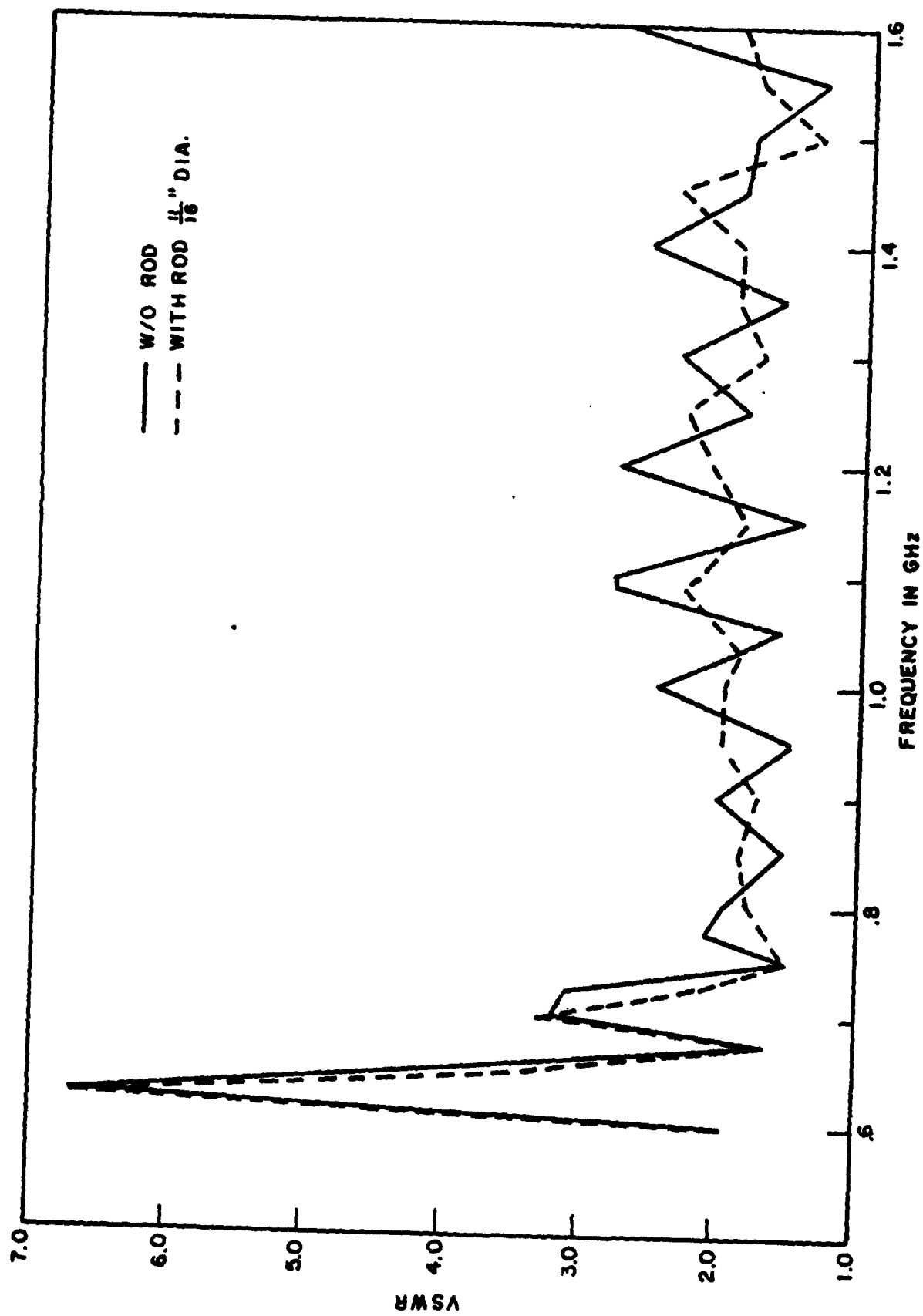


Fig. 12 — Modified AS-1065 antenna: VSWR vs frequency

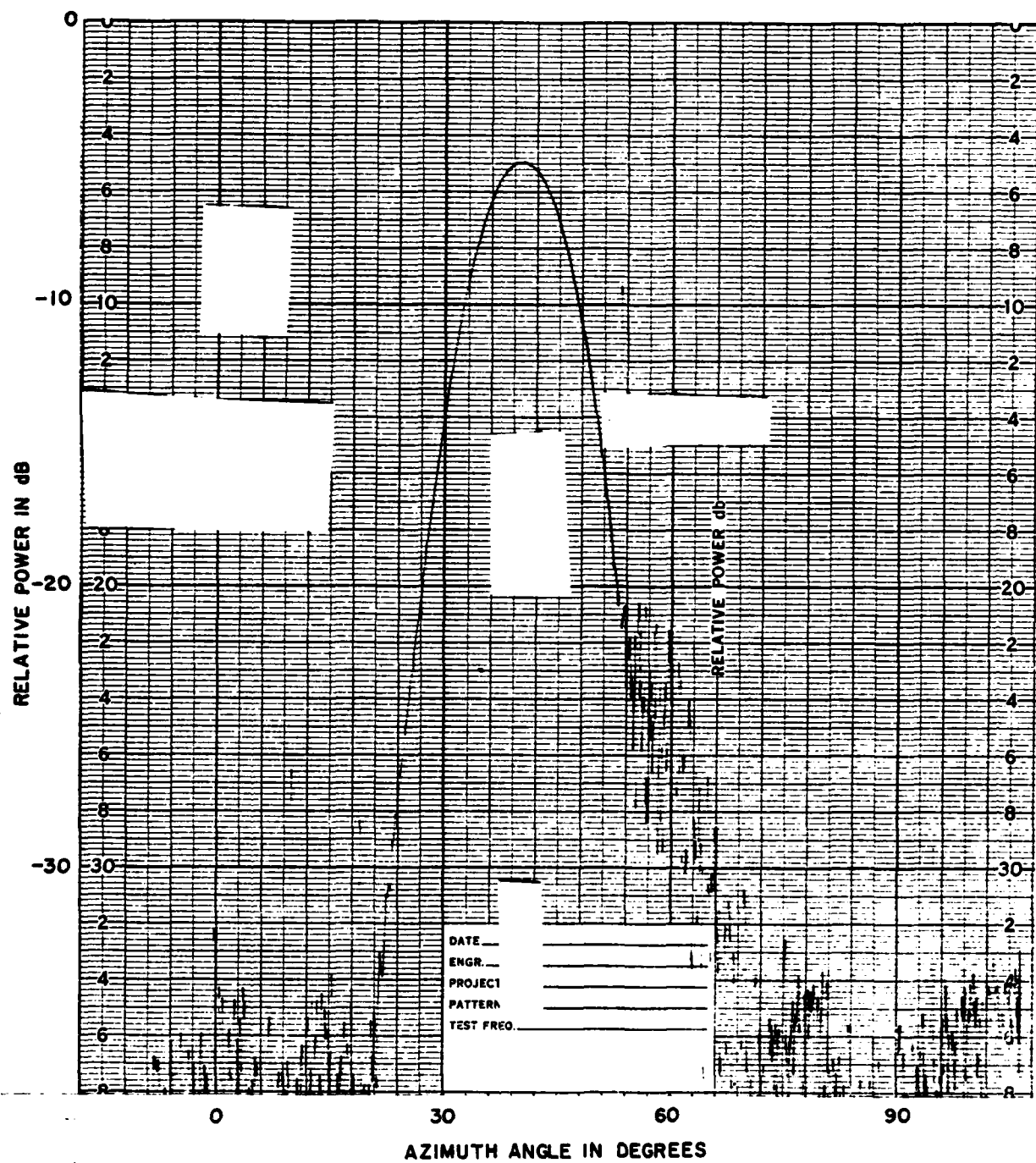


Fig. 13 — Radiation pattern of the modified pillbox AS-1065 antenna at 600 MHz

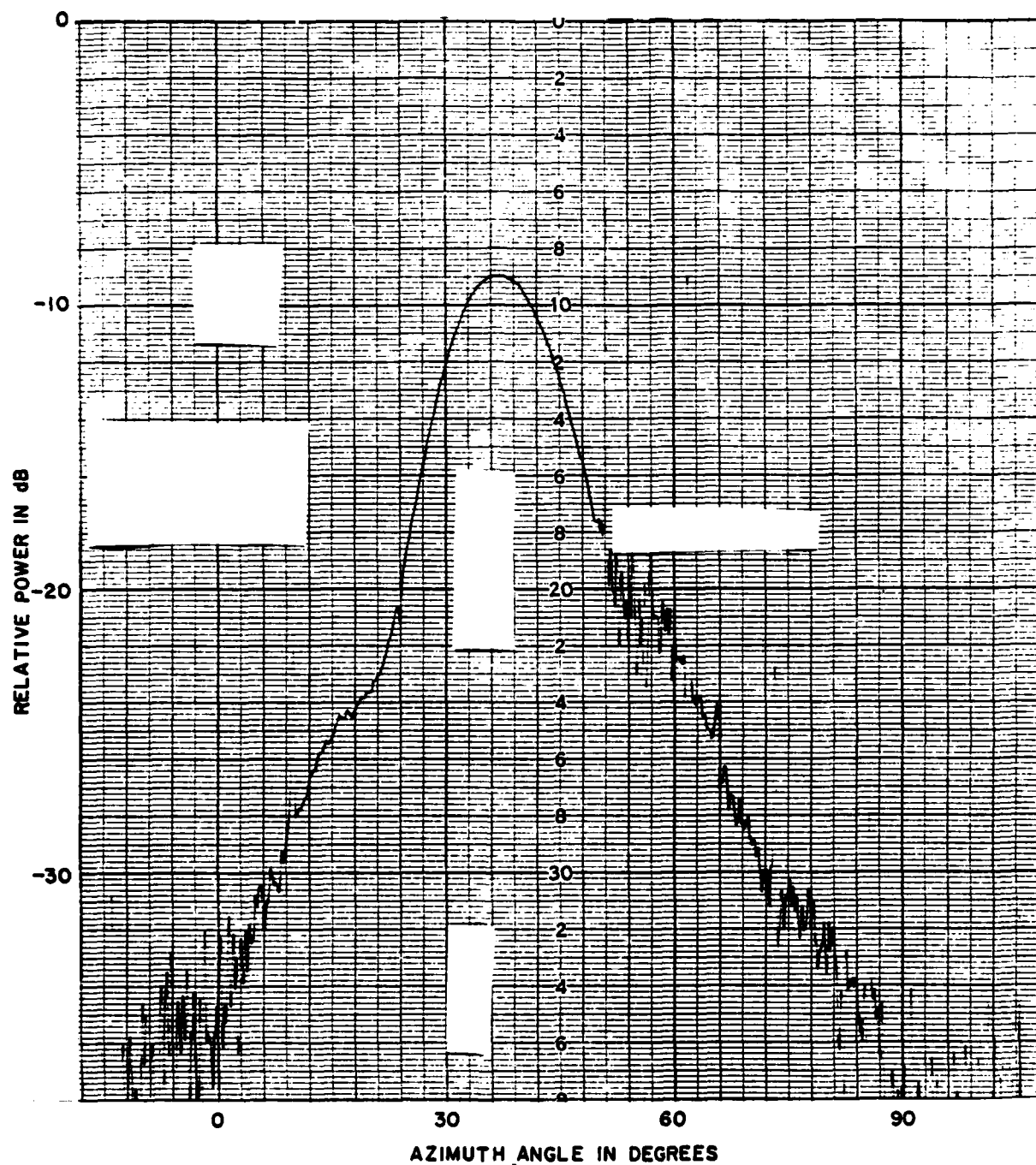


Fig. 14 — Radiation pattern of the modified pillbox AS-1065 antenna at 700 MHz

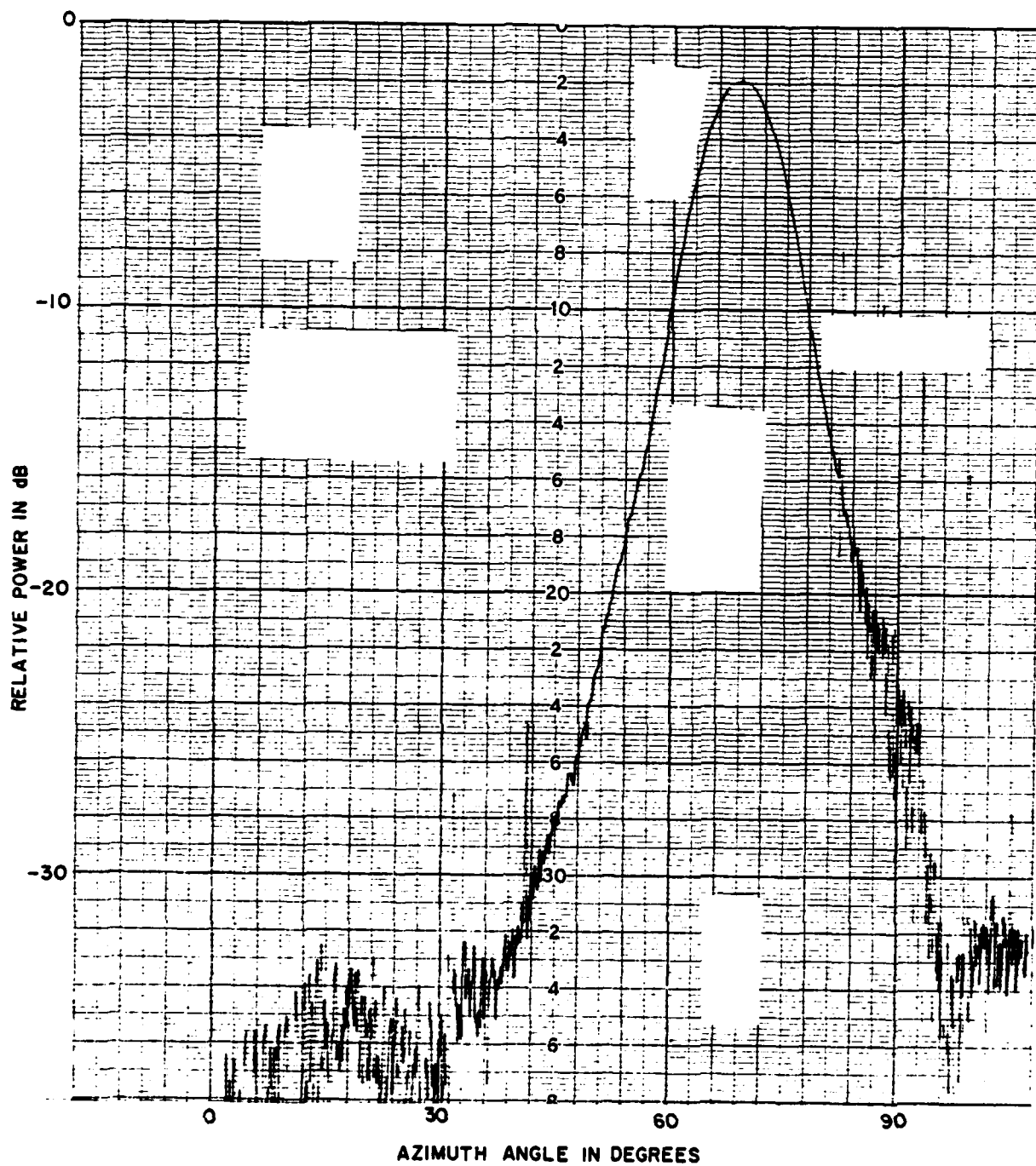


Fig. 15 — Radiation pattern of the modified pillbox AS-1065 antenna at 800 MHz

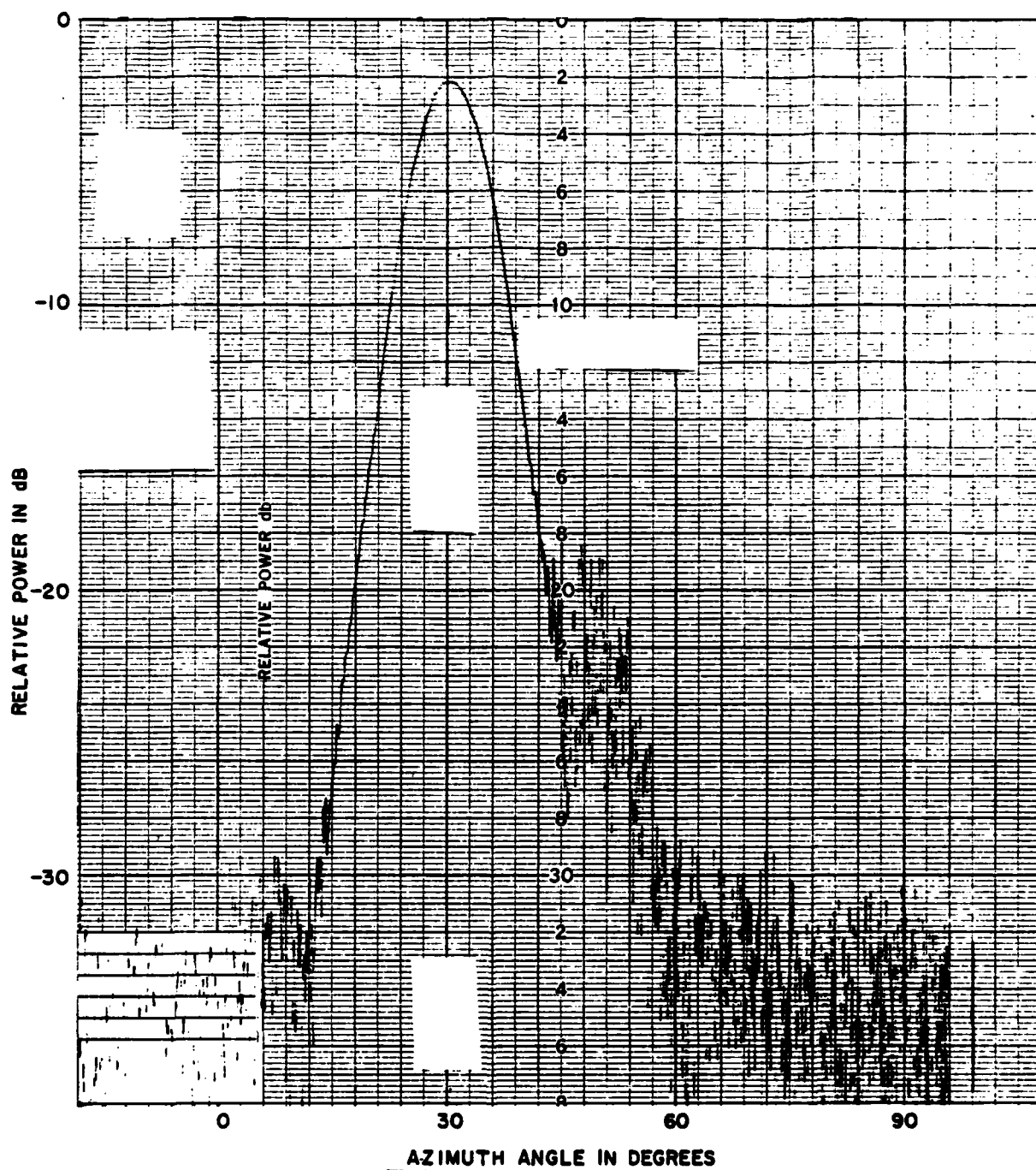


Fig. 16 — Radiation pattern of the modified pillbox AS-1065 antenna at 900 MHz

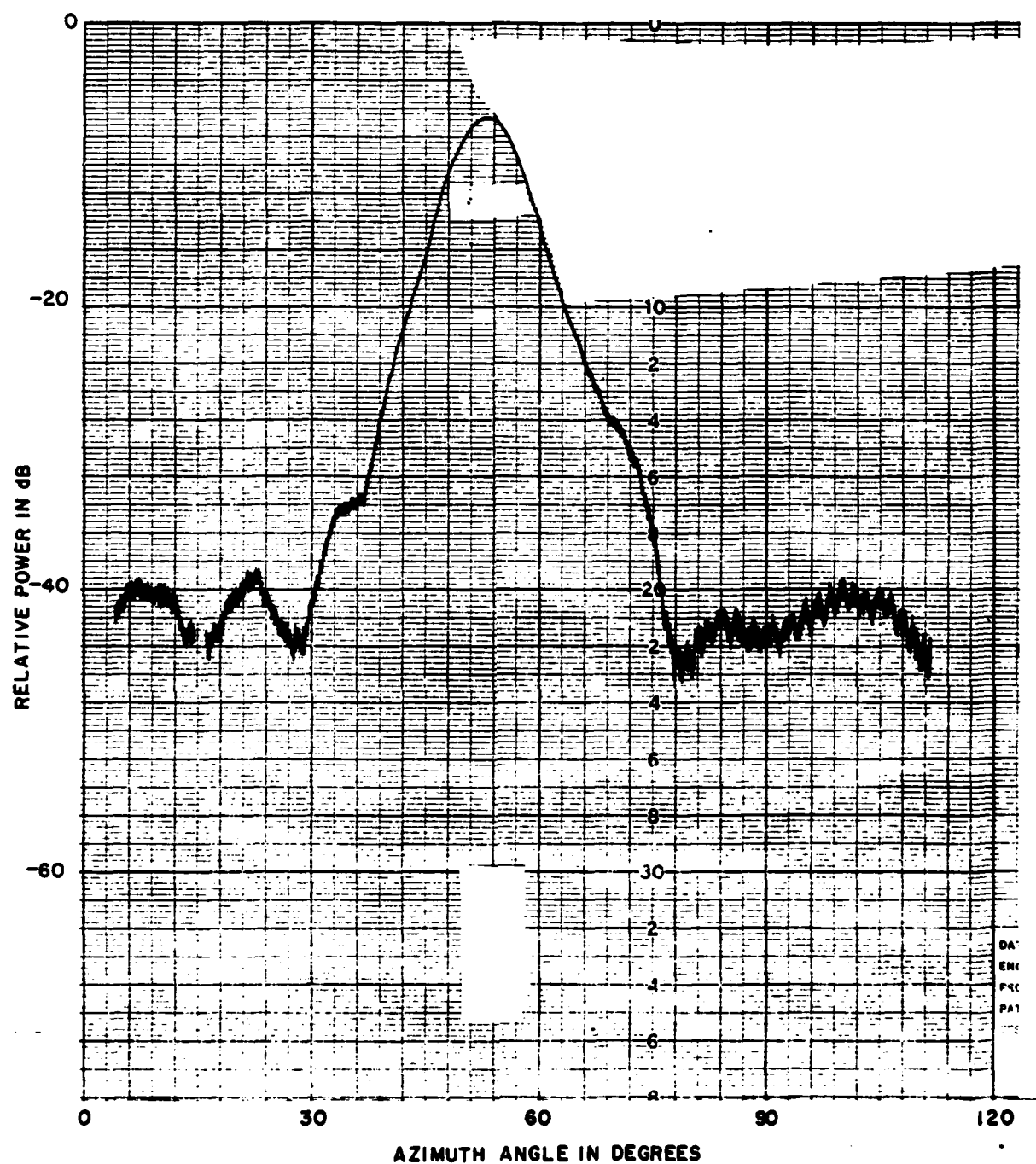


Fig. 17 — Radiation pattern of the modified pillbox AS-1065 antenna at 1000 MHz

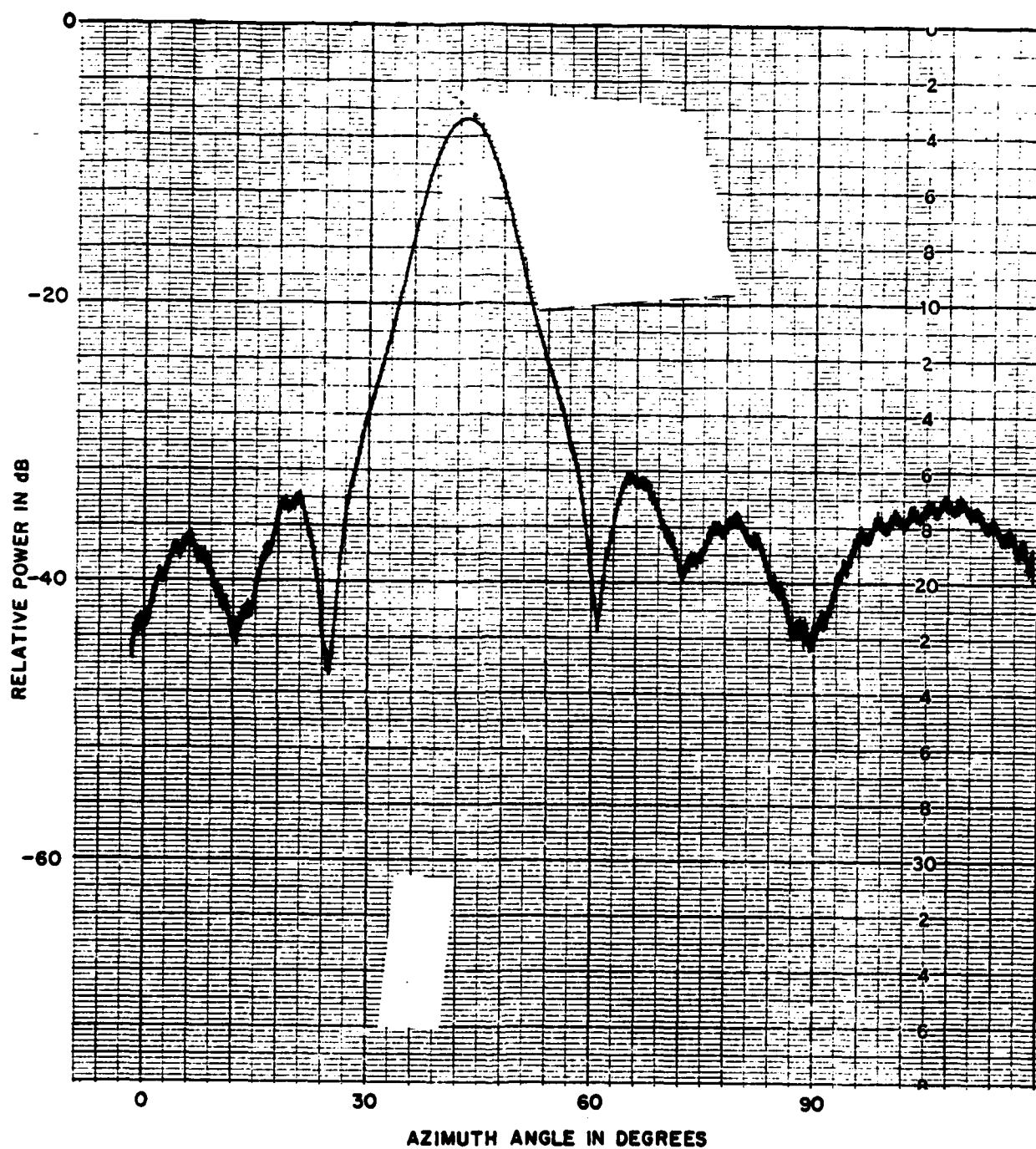


Fig. 18 — Radiation pattern of the modified pillbox AS-1065 antenna at 1100 MHz

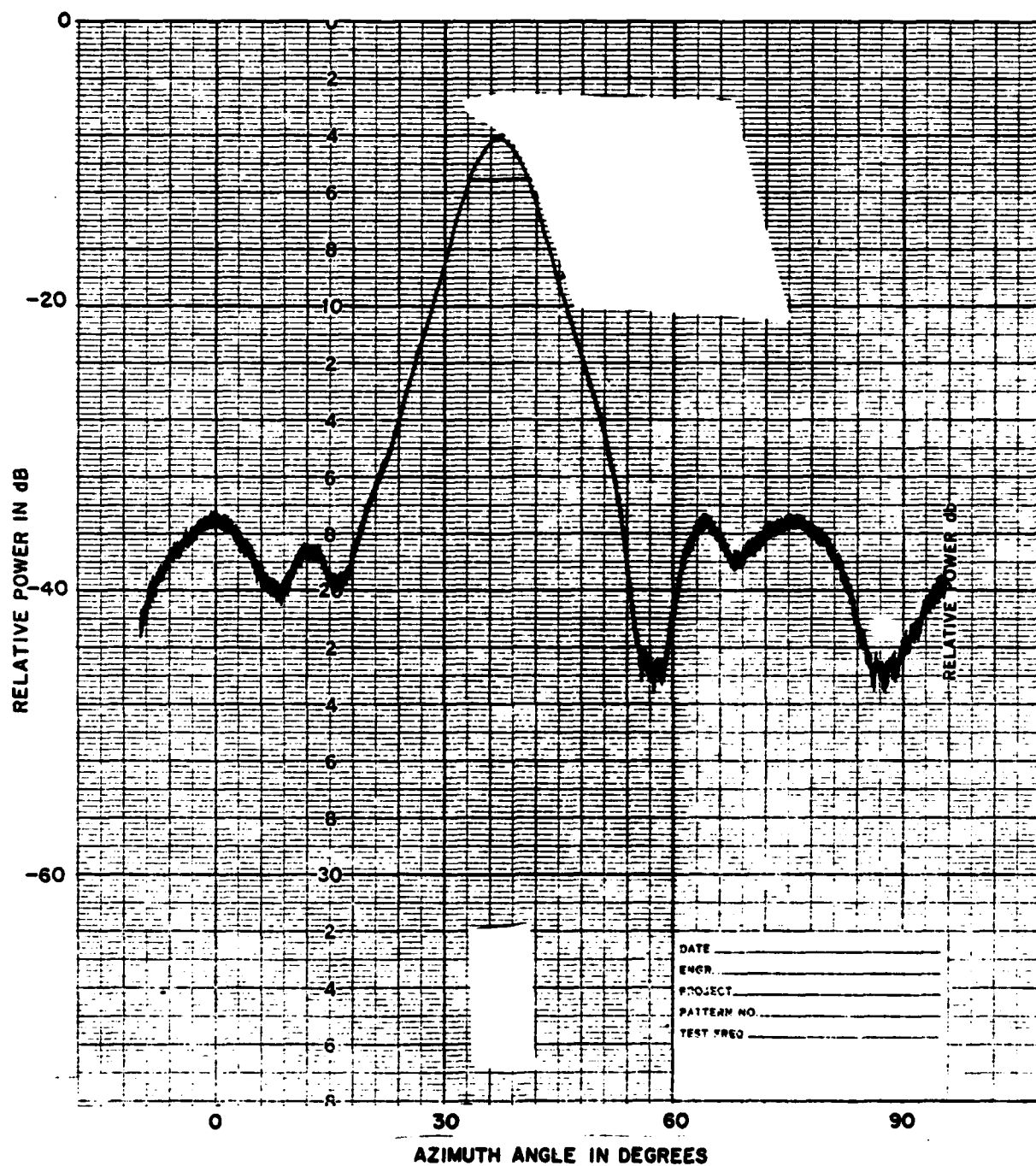


Fig. 19 — Radiation pattern of the modified pillbox AS-1065 antenna at 1200 MHz

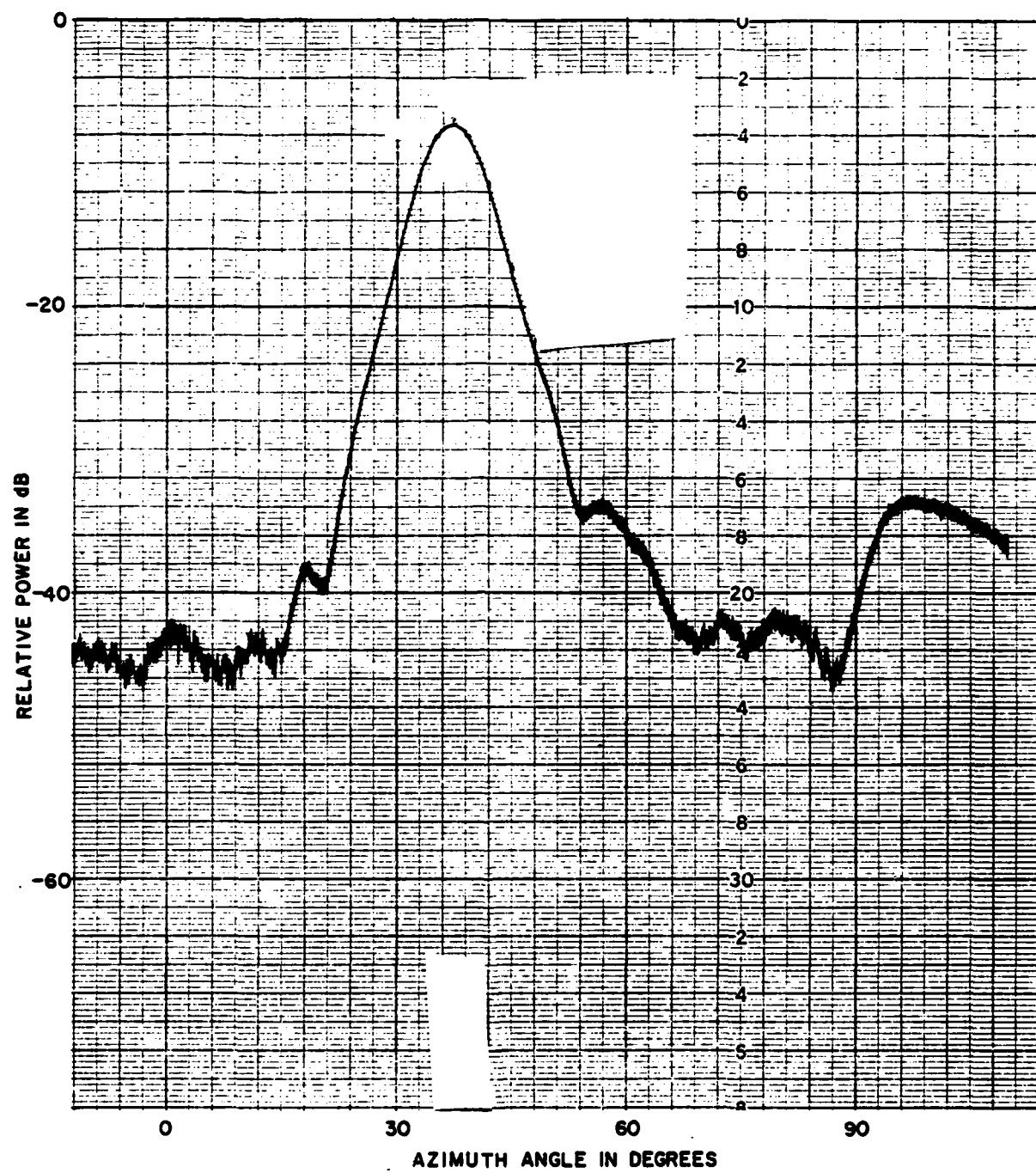


Fig. 20 — Radiation pattern of the modified pillbox AS-1065 antenna at 1300 MHz

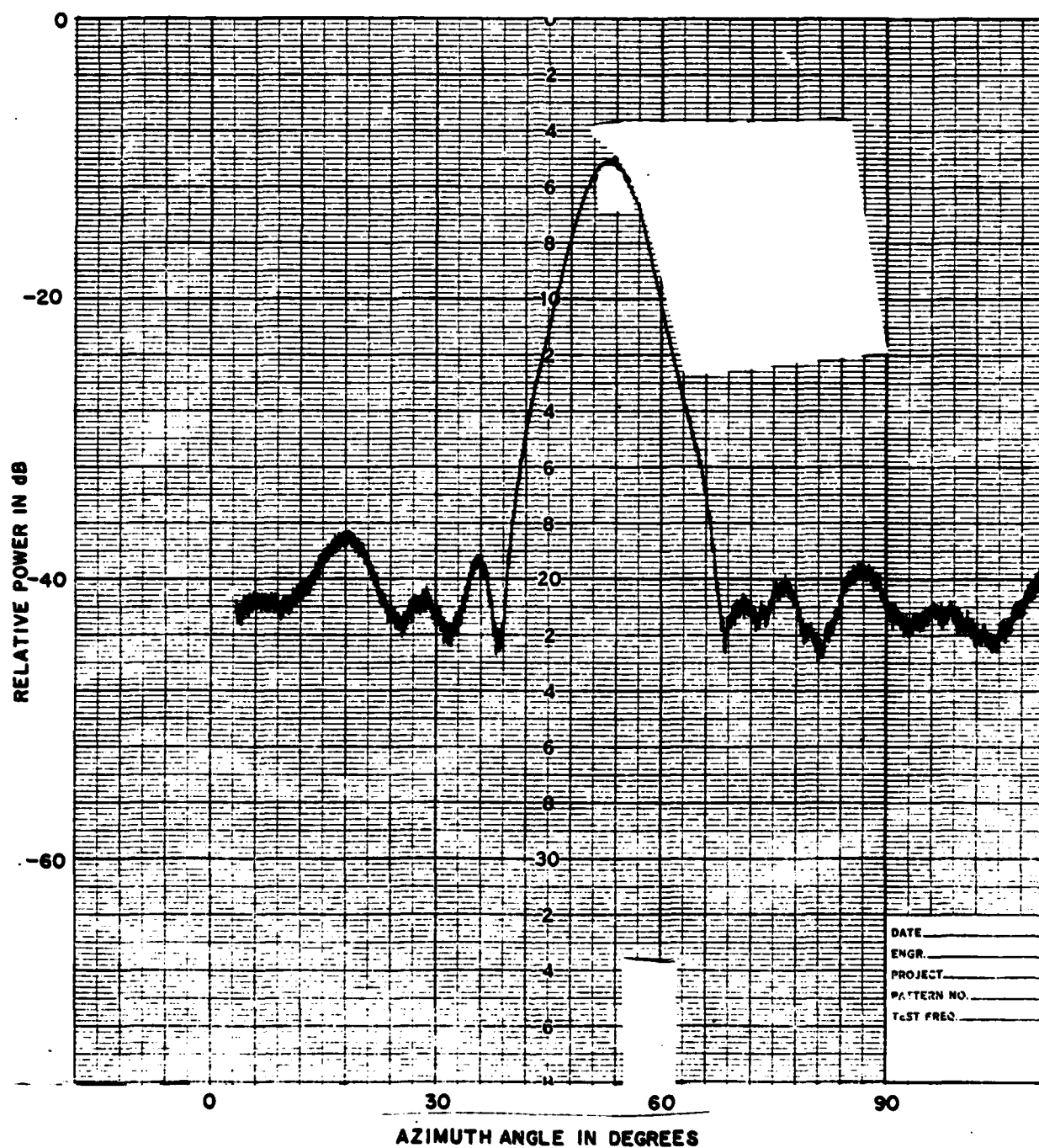


Fig. 21 — Radiation pattern of the modified pillbox AS-1065 antenna at 1400 MHz

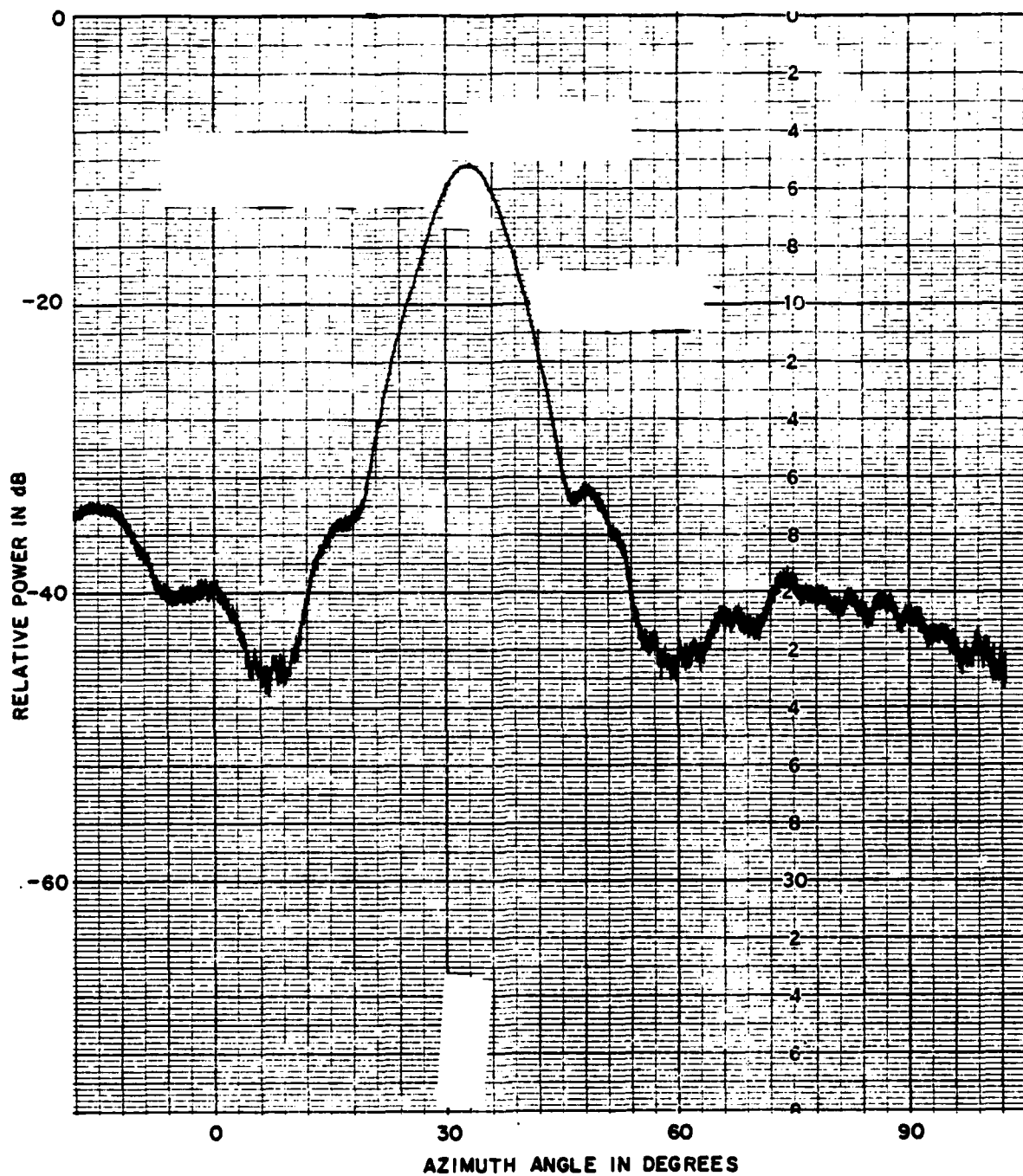


Fig. 22 — Radiation pattern of the modified pillbox AS-1065 antenna at 1500 MHz

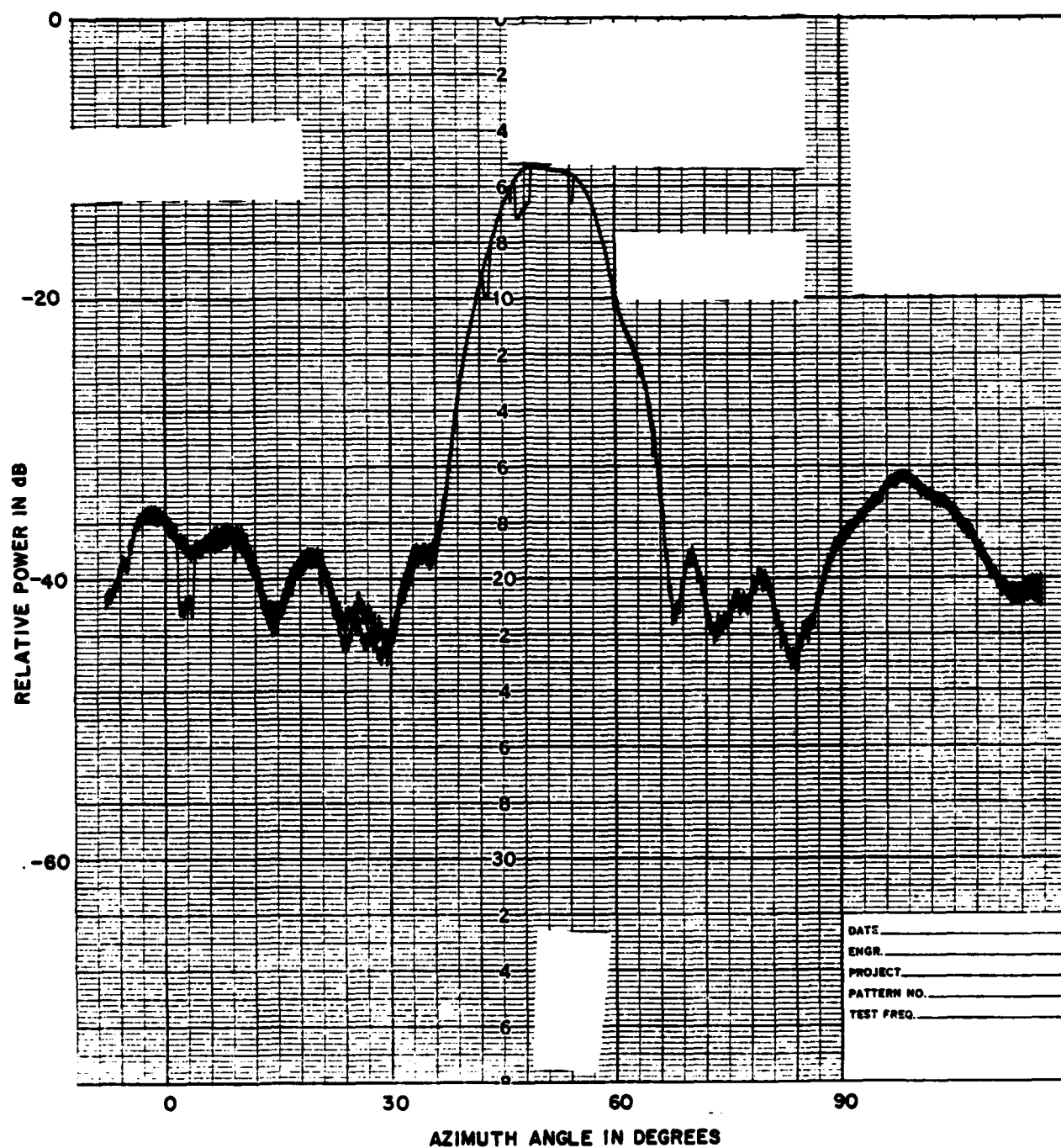


Fig. 23 — Radiation pattern of the modified pillbox AS-1065 antenna at 1600 MHz

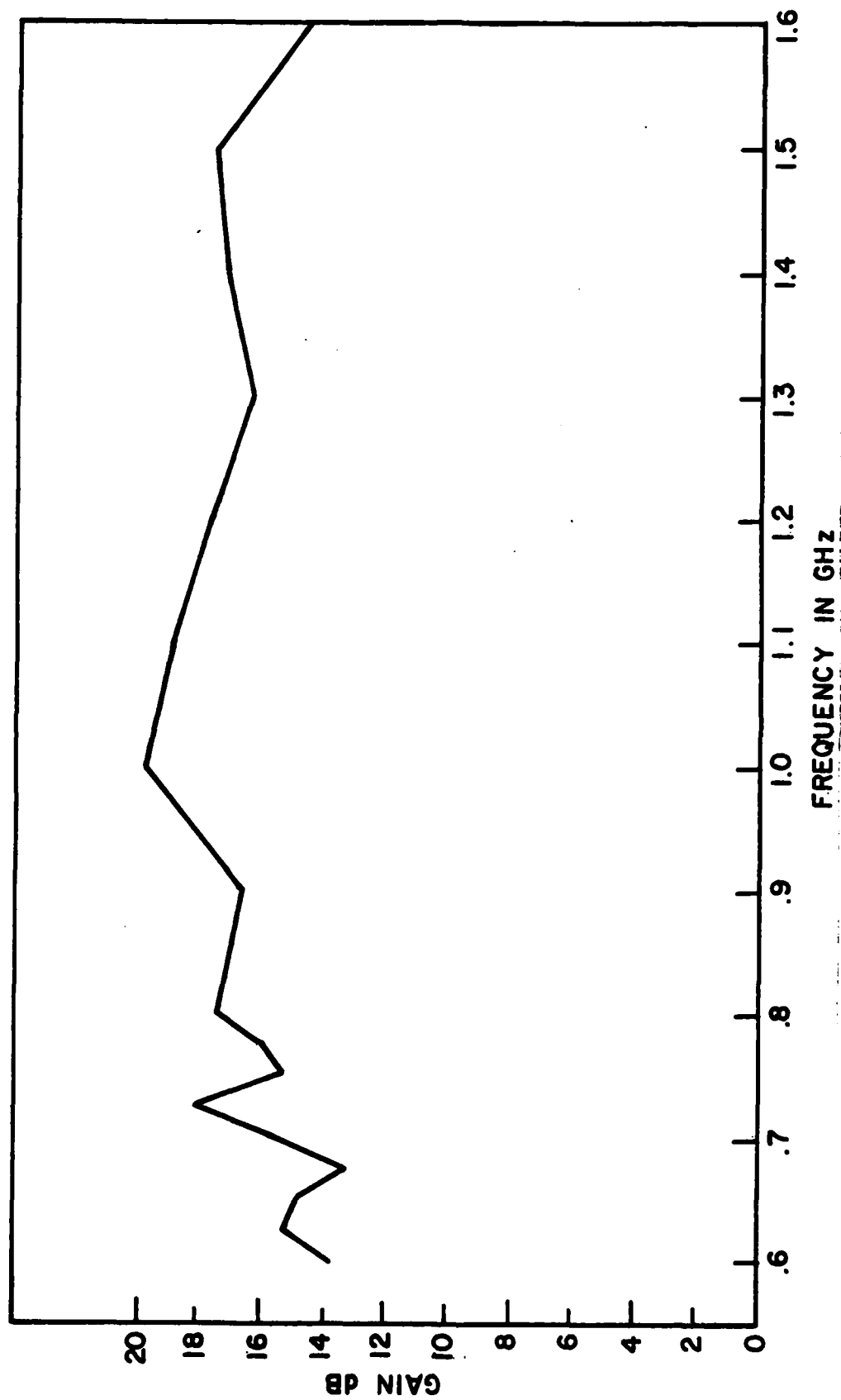


Fig. 24 — Absolute gain vs frequency for modified AS-1065 antenna

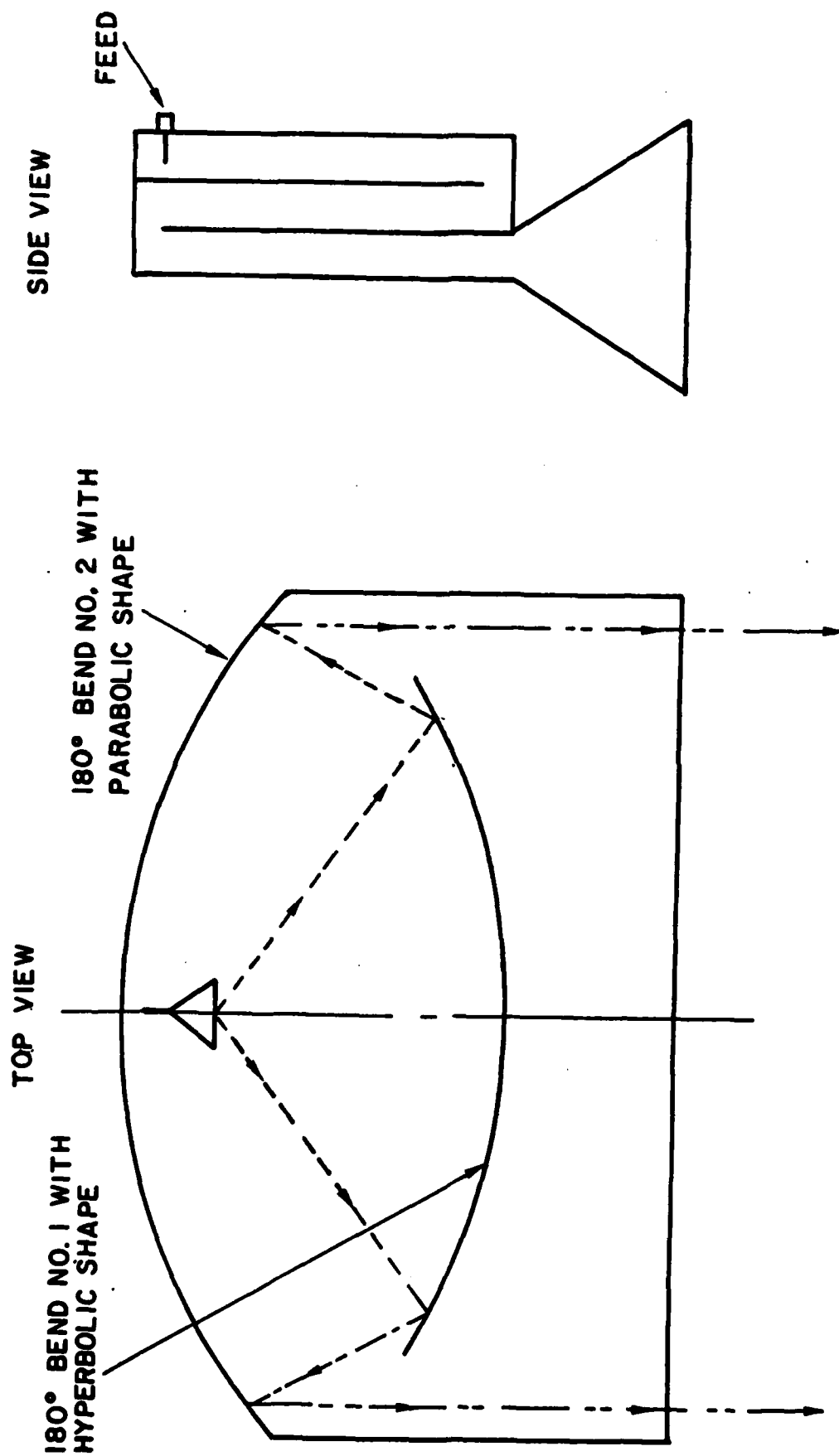


Fig. 25 — Triple layer pillbox

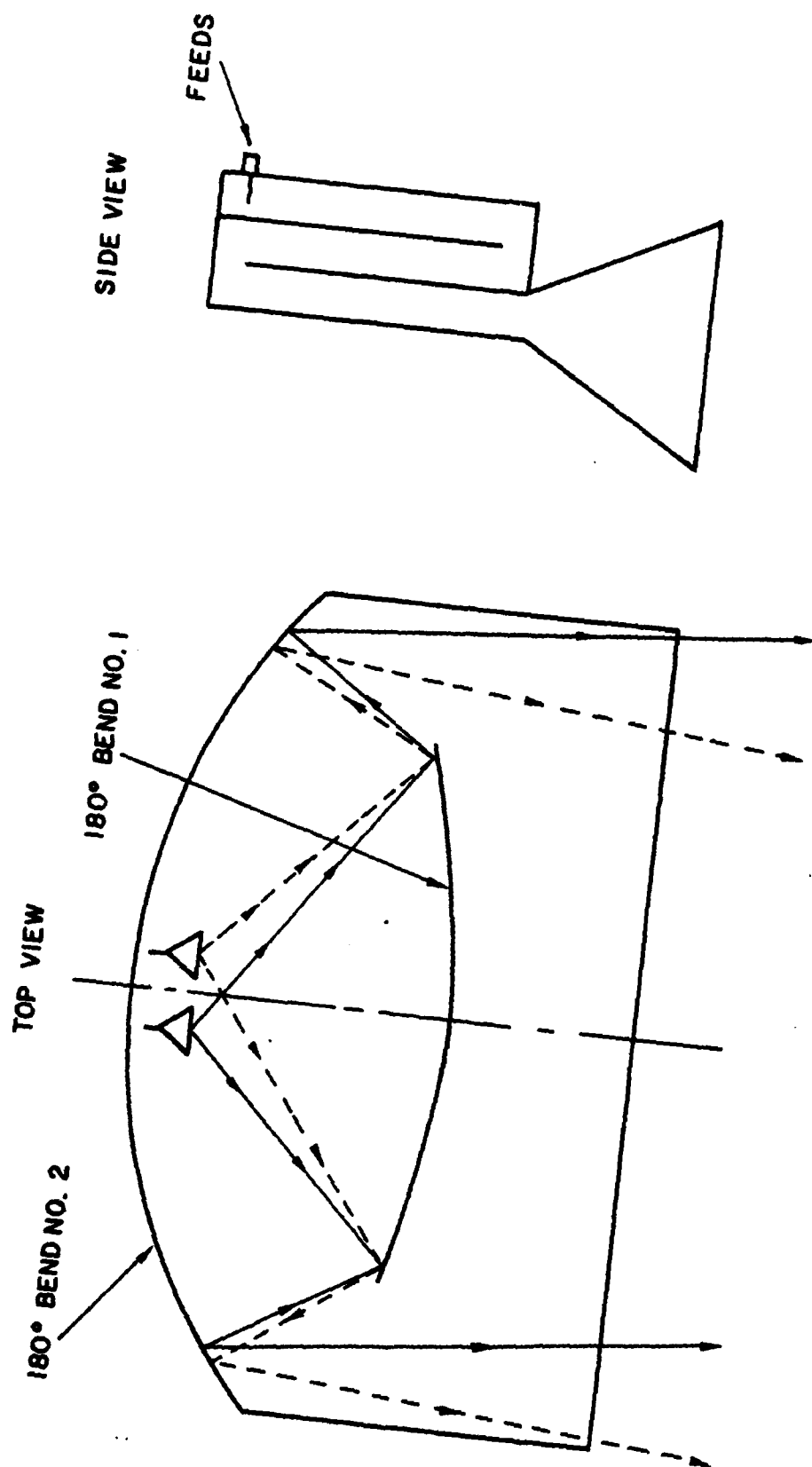


Fig. 26 -- Bifocal triple layer pillbox

